Air Quality Modeling for the HD 2027 Proposal

Draft Technical Support Document (TSD)

United States
Environmental Protection
Agency

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

EPA United States Environmental Protection Agency

EPA-420-D-22-002
February 2022

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1 Introduction/Overview

The Environmental Protection Agency (EPA) is proposing a rule to build on and improve the existing emission control program for on-highway heavy-duty engines and vehicles by further reducing air pollution from heavy-duty engines across the United States. This proposed rulemaking is formally titled “Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine Standards,” and was formerly more generally referred to as the "Cleaner Trucks Initiative" (CTI). The proposed rule would lower emissions of NO_x and other pollutants (particulate matter (PM), volatile organic compounds (VOCs), air toxics, and carbon monoxide (CO)). This document includes information related to the air quality modeling analysis done in support of the proposed rule.

For this analysis, emission inventories were produced, and air quality modeling was performed, for three scenarios: a year 2016 base case, a year 2045 reference scenario, and a year 2045 control scenario. The "reference" scenario represents projected 2045 emissions and air quality without the proposed rule and the "control" scenario represents projected 2045 emissions and air quality with proposed Option 1.[1] The emissions used for the 2045 control scenario were the same as those in the 2045 reference scenario for all emissions sectors except for the onroad mobile source emissions.

An air quality modeling platform consists of all the emissions inventories and ancillary data files used for emissions modeling, as well as the meteorological, initial condition, and boundary condition files needed to run the air quality model. An emissions modeling platform consists of the emissions modeling data and techniques including the emission inventories, the ancillary data files, and the approaches used to transform inventories for use in air quality modeling.

This analysis utilizes the Inventory Collaborative 2016v1 emissions modeling platform,[2] which includes a suite of base year (2016) and projection year (2028) inventories, along with ancillary emissions data, and scripts and software for preparing the emissions for air quality modeling. The National Emissions Inventory Collaborative is a partnership between state emissions inventory staff, multi-jurisdictional organizations (MJOs), federal land managers (FLMs), EPA, and others to develop a North American air pollution emissions modeling platform with a base year of 2016 for use in air quality planning. The Technical Support Document (TSD) Preparation of Emissions Inventories for the 2016v1 North American Emissions Modeling Platform describes how the 2016 and 2028 emission inventories for the platform were developed.[3]

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[1] As noted in Chapter 5.4 of the draft RIA, while we refer to this modeling as for the proposed Option1, there are differences between the proposed Option 1 standards, emission warranty, and useful life provisions presented in Sections III and IV of the preamble and those included in the control scenario modeled for the air quality analysis.

[2] National Emissions Inventory Collaborative (2019). 2016v1 Emissions Modeling Platform. Retrieved from http://views.cira.colostate.edu/wiki/wiki/10202.

[3] U.S. EPA (2021) Preparation of Emissions Inventories for 2016v1 North American Emissions Modeling Platform Technical Support Document. https://www.epa.gov/csapr/preparation-emissions-inventories-2016v1-north-american-emissions-modeling-platform-technical.

Preparing projected emission inventories is a complex process. There is not much information available about potential changes to stationary source emissions for years after 2030. Because of this lack of information and because this rulemaking is focused on onroad mobile sources, the decision was made to use the collaboratively-developed emission inventories for 2028 in the 2045 cases except for U.S. onroad and nonroad mobile sources, and for onroad mobile sources in Canada and Mexico. Section 2 of this document gives a summary of the emissions inventory inputs to the air quality modeling. Section 3 of this document describes the methodology for developing onroad mobile emission inventories and Section 4 provides emissions summary tables. Sections 5 and 6 provide an overview of the air quality modeling methodology and results.

2 Emissions Inventory Methodology

This section provides an overview of the emission inventories used in the air quality analysis for the proposed rule. These inventories include point sources, nonpoint sources, onroad and nonroad mobile sources, commercial marine vessels (CMV), locomotive and aircraft emissions, biogenic emissions, and fires for the U.S., Canada, and Mexico. For this study, the 2016 emission inventories used were the same as those for the 2016v1 platform except for the U.S. onroad mobile sources. For the 2045 cases, the U.S. onroad mobile sources, U.S. nonroad mobile sources, and onroad mobile sources for Canada and Mexico were projected to year 2045 levels, while other anthropogenic emissions sources were retained at the 2016v1 platform projected emissions levels for the year 2028. A high-level summary of the emission inventories used is provided in this section, while the development of the U.S. onroad mobile source emissions is described in detail in Section 3.

2.1 Emissions Inventory Sector Summary

For the purposes of preparing the air quality model-ready emissions, emission inventories are split into “sectors”. The significance of a sector is that each sector includes a specific group of emission sources, and those data are run through the emissions modeling system independently from the other sectors up to the point of the final merging process. The final merge process combines the sector-specific low-level (of the vertical levels in the AQ model) gridded, speciated, hourly emissions together to create CMAQ-ready emission inputs. While pertinent atmospheric emissions related to the problem being studied are included in each modeling platform, the splitting of inventories into specific sectors for emissions modeling varies by platform. The sectors for the 2016v1 emissions modeling platform are used in this study and are shown in Table 2-1. Descriptions for each sector are provided. For more detail on the data used to develop the inventories and on the processing of those inventories into air quality model-ready inputs, see the 2016v1 emissions modeling platform TSD.[3]

Table 2-1 Inventory sectors included in the 2016v1 emissions modeling platform

Inventory Sector	Sector Description

Mobile - Nonroad	Mobile sources that do not drive on roads excluding locomotives, aircraft, and commercial marine vessels (see Section 2.3)
Mobile - Onroad	Onroad mobile source gasoline and diesel vehicles from moving and non-moving vehicles that drive on roads (see Section 3)
Mobile – Category 3 Commercial Marine Vessels	Commercial marine vessels with Category 3 engines within and outside of U.S. waters
Mobile – Category 1 and 2 Commercial Marine Vessels	Commercial marine vessels with Category 1 and 2 engines within and outside of U.S. waters
Mobile - Rail	U.S. Class I line haul, Class II/III line haul, passenger, and commuter locomotives (does not include railyards and switchers)
Nonpoint - Agriculture	NH_3 and VOC emissions from U.S. livestock and fertilizer sources
Nonpoint – Area Fugitive Dust	PM emissions from paved roads, unpaved roads and airstrips, construction, agriculture production, and mining and quarrying in the U.S.
Nonpoint – Residential Wood Combustion	U.S. residential wood burning emissions from devices such as fireplaces, woodstoves, pellet stoves, indoor furnaces, outdoor burning in fire pits and chimneys
Nonpoint - Oil and Gas	Oil and gas exploration and production, both onshore and offshore
Nonpoint - Other	All nonpoint emissions in the U.S. not included in other sectors, including solvents, industrial processes, waste disposal, storage and transport of chemicals and petroleum, waste disposal, commercial cooking, and miscellaneous area sources
Point – Airports	Aircraft engines and ground support equipment at U.S. airports
Point – Electrical Generating Units	Electric generating units that provide power to the U.S. electric grid
Point – Oil and Gas	Point sources related to the extraction and distribution of oil and gas in the U.S.
Point – Other	All point sources in the U.S. not included in other sectors. Includes rail yards.
Point – Fires – Agricultural	Fires due to agricultural burning in the U.S.
Point – Fires – Wild and Prescribed	Wildfires and prescribed burns in the U.S.
Point – Non-U.S. Fires	Fires within the domain but outside of the U.S.
5Biogenic (beis)	Emissions from trees, shrubs, grasses, and soils within and outside of the U.S.
Canada – Mobile - Onroad	Onroad mobile sources in Canada (see Section 2.5)
Mexico – Mobile - Onroad	Onroad mobile sources in Mexico (see Section 2.5)
Canada/Mexico - Point	Canadian and Mexican point sources
Canada/Mexico - Nonpoint and Nonroad	Canadian and Mexican nonpoint and nonroad sources
Canada – Nonpoint – Area Fugitive Dust	Area source fugitive dust sources in Canada
Canada – Point – Point Fugitive Dust	Point source fugitive dust sources in Canada

2.2 The Emissions Modeling Process

The CMAQ air quality model requires hourly emissions of specific gas and particle species for the horizontal and vertical grid cells contained within the modeled region (i.e., modeling domain). To provide emissions in the form and format required by the model, it is necessary to “pre-process” the emissions inventories for the sectors described above. The process of emissions modeling transforms the emissions inventories from their original temporal, pollutant, and spatial resolution into the hourly, speciated, gridded resolution required by the air quality model. Emissions modeling includes the chemical speciation, temporal allocation, and spatial allocation of emissions along with final formatting of the data that will be input to the air quality model.

Chemical speciation creates the "model species" needed by CMAQ, for a specific chemical mechanism, from the "inventory pollutants" of the input emission inventories. These model species are either individual chemical compounds (i.e., "explicit species") or groups of species (i.e., "lumped species"). The chemical mechanism used for this platform is the CB6 mechanism.[4] This platform generates the $PM_{2.5}$ model species associated with the CMAQ Aerosol Module version 7 (AE7). See Section 3.2 of the 2016v1 platform TSD for more information about chemical speciation in the 2016v1 platform.

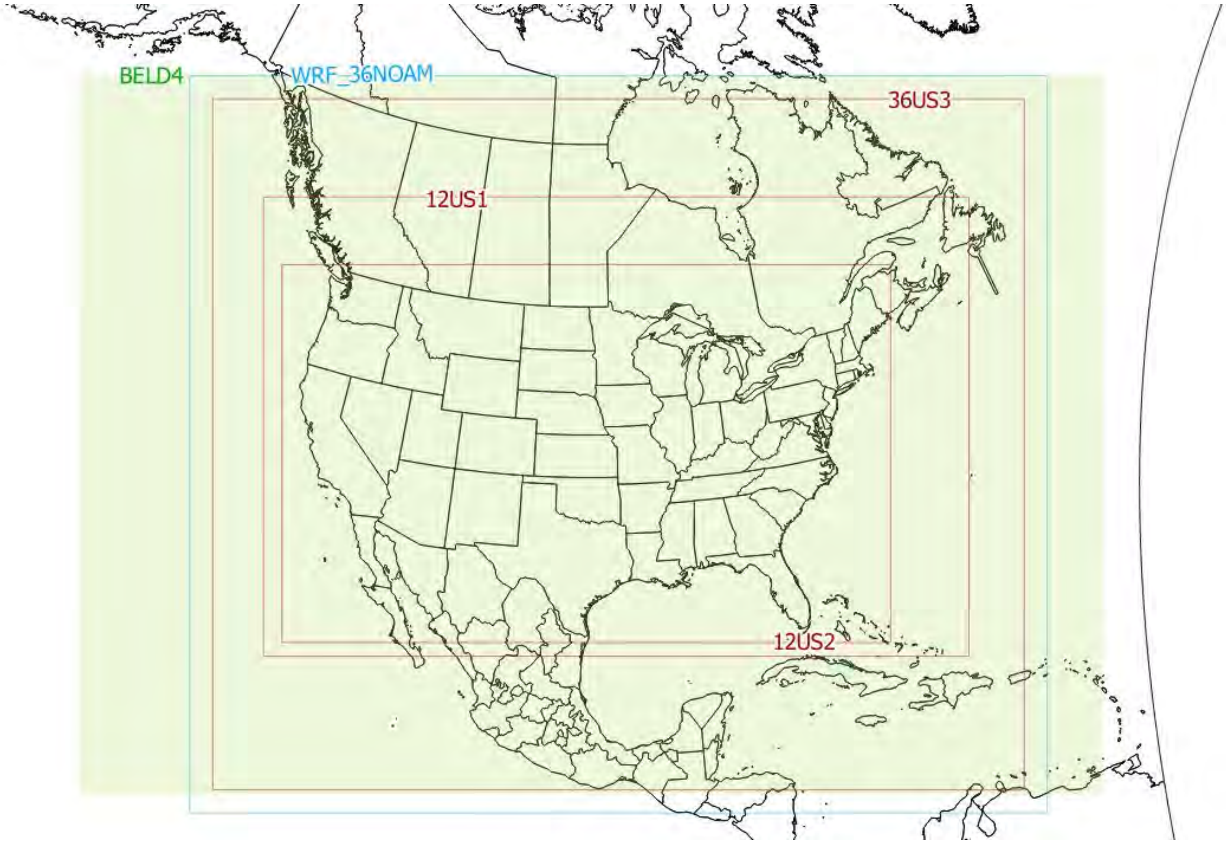
Temporal allocation is the process of distributing aggregated emissions to a finer temporal resolution, for example converting annual emissions to hourly emissions as is required by CMAQ. While the total annual, monthly, or daily emissions are important, the hourly timing of the occurrence of emissions is also essential for accurately simulating ozone, PM, and other pollutant concentrations in the atmosphere. Many emissions inventories are annual or monthly in nature. Temporal allocation takes these aggregated emissions and distributes the emissions to the hours of each day. This process is typically done by applying temporal profiles to the inventories in this order: monthly, day of the week, and diurnal, with monthly and day-of-week profiles applied only if the inventory is not already at that level of detail. See Section 3.3 of the 2016v1 platform TSD for more information about temporal allocation of emissions in the 2016v1 platform.

Spatial allocation is the process of distributing aggregated emissions to a finer spatial resolution, as is required by CMAQ. Over 60 spatial surrogates are used to spatially allocate U.S. county-level emissions to the12-km grid cells used by the air quality model. See Section 3.4 of the 2016v1 platform TSD for a description of the spatial surrogates used for allocating county-level emissions in the 2016v1 platform.

The primary tool used to perform the emissions modeling to create the air quality model-ready emissions was the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system, version 4.7 (SMOKE 4.7) with some updates. When preparing emissions for CMAQ, emissions for each sector are processed separately through SMOKE. The elevated point source emissions are passed to CMAQ directly so the model can perform plume rise based on hourly meteorological conditions, while the low-level emissions are combined to create model-ready 2-D gridded emissions. Gridded emissions files were created for a 36-km national grid named 36US3 and for a 12-km national grid named 12US2, both of which include the contiguous states and parts of Canada and Mexico as shown in Figure 2-1. This figure also shows the region covered by other grids that are relevant to the development of emissions for this and related studies.

[4] Yarwood, G., et al. (2010) Updates to the Carbon Bond Chemical Mechanism for Version 6 (CB6). Presented at the 9th Annual CMAS Conference, Chapel Hill, NC. Available at https://www.cmascenter.org/conference/2010/abstracts/emery_updates_carbon_2010.pdf.

Figure 2-1 Air quality modeling domains



2.3 Emissions Inventory Methodology for 2016v1-Compatible Sectors

Except for the onroad mobile source emissions, the emissions used for the 2016 air quality case are consistent with those developed through the 2016v1 Collaborative Platform. For the 2045 cases, emissions for sectors other than U.S. onroad and nonroad mobile sources and emissions for onroad mobile sources for Canada and Mexico, were developed to be consistent with the 2028 emissions developed by the Inventory Collaborative and are described in the 2016v1 Platform TSD. Development of the 2045 nonroad and Canada and Mexico onroad emissions are described in Sections 2.4 and 2.5. The development of the onroad mobile source emissions for each of the cases is described below in Section 3.

2.4 2045 Emissions Inventory Methodology for the Nonroad Sector

To prepare the nonroad mobile source emissions, the version of Motor Vehicle Emission Simulator (MOVES) developed for this NPRM – MOVES_CTI_NPRM – was run using inputs compatible with the 2016v1 platform. The nonroad component of MOVES was configured to create a national nonroad inventory for 2045. The 2045 MOVES nonroad inventory was used in all states except California and Texas.

For California, the California Air Resources Board (CARB) provided nonroad emissions for several years for inclusion in the 2016v1 platform. The latest year of nonroad emissions provided by CARB was 2035. To prepare the 2045 inventories, the MOVES-based emissions in

California from 2035 and 2045 were used to project the CARB 2035 nonroad inventory to 2045. Projection factors were based on ratios of MOVES emissions (i.e., 2045/2035) to reflect the MOVES trends between those two years by county, SCC, and pollutant.

For Texas, the Texas Commission on Environmental Quality (TCEQ) provided nonroad emissions for several years for use in the 2016v1 platform, including 2016. The latest year of nonroad emissions provided by TCEQ was 2028. The 2028 TCEQ nonroad emissions were projected to 2045 based on MOVES trends between those two years by county, SCC, and pollutant.

2.5 2045 Emissions Inventory Methodology for Canada and Mexico Onroad Sectors

For Canada onroad emissions, the base year inventory provided by Environment and Climate Change Canada for use in the 2016v1 platform was projected to 2045. Projection factors were based on total contiguous U.S. onroad emissions totals from 2016 and 2045 from the version of MOVES used to prepare onroad emissions for this notice of proposed rulemaking (MOVES_CTI_NPRM).[5] Projection factors specific to fuel type, MOVES source type, road type, mode (exhaust/evaporative), and pollutant, were applied equally across Canada.

Mexico onroad mobile source emissions were developed by running the MOVES-Mexico model for 2045.[6]

3 Onroad Emissions Inventory Methodology

This section focuses on the approach and data sources used to develop gridded, hourly emissions for the onroad mobile sector that are suitable for input to an air quality model in terms of the format, grid resolution, and chemical species. While the emission factors used to develop emissions for the reference and control scenarios differed, the approach and all other data sources used to calculate emissions for both scenarios were identical.

Onroad mobile source emissions result from motorized vehicles operating on public roadways. These include passenger cars, motorcycles, minivans, sport-utility vehicles, light-duty trucks, heavy-duty trucks, and buses. The sources are further divided by the fuel they use, including diesel, gasoline, E-85, and compressed natural gas (CNG) vehicles. The sector characterizes emissions from parked vehicle processes (e.g., starts, hot soak, and extended idle) as well as from on-network processes (i.e., from vehicles as they move along the roads). The onroad emissions are generated using SMOKE programs that leverage MOVES-generated emission factors with county, fuel type, source type, and road type-specific activity data, along with hourly meteorological data.

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[5] An inventory of onroad emissions in Canada was available for 2028, but MOVES_CTI_NPRM was not run for 2028, so it was not possible to develop 2028-2045 projection factors based directly on MOVES_CTI_NPRM. Instead, 2016 was used as the base year for the Canada projections.

[6] USAID, 2016. Adaptation of the Vehicle Emission Model MOVES to Mexico. Available from: https://www.epa.gov/sites/default/files/2021-03/documents/usaid-inecc-2016-01-31.pdf.

The MOVES-generated onroad emission factors were combined with activity data (e.g., vehicle miles traveled, vehicle population) to produce emissions within the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system. The collection of programs that compute the onroad mobile source emissions are known as SMOKE-MOVES. SMOKE-MOVES uses a combination of vehicle activity data, emission factors from MOVES, meteorology data, and temporal allocation information needed to estimate hourly onroad emissions. Additional types of ancillary data are used for the emissions processing, such as spatial surrogates which spatially allocate emissions to the grid used for air quality modeling.

More details on the generation of the emission factors, activity data, and on the modeling of the emissions are in the following subsections. National onroad emission summaries for key pollutants are provided in Section 4.

3.1 Emissions Factor Table Development

Onroad mobile source emission factors were generated for each of the modeled cases by running MOVES_CTI_NPRM, the version of MOVES that incorporates updates relevant to the analyses needed for this rulemaking. MOVES_CTI_NPRM estimated onroad exhaust and evaporative emission rates at the county level. MOVES_CTI_NPRM incorporates data from a wide range of test programs and other sources, see the draft Regulatory Impact Analysis (DRIA) chapter 5. For example, the onroad emission rates are based on a detailed analysis of in-use emissions from hundreds of heavy-duty trucks.[7]

The emission factor tables input to SMOKE-MOVES are generated by running MOVES. These tables differentiate emissions by process (i.e., running, start, vapor venting, etc.), fuel type, vehicle type, road type, temperature, speed bin for rate per distance processes, hour of day, and day of week. To generate the MOVES emission factors across the U.S., MOVES was run to produce emission factors for a series of temperatures and speeds for a set of "representative counties," to which every other county in the country is mapped. The representative counties for which emission factors are generated are selected according to their state, elevation, fuels used in the region, vehicle age distribution, and inspection and maintenance programs. Every county in the country is mapped to a representative county based on its similarity to the representative county with respect to those attributes. The representative counties were reanalyzed for the 2016v1 platform according to each of the criteria and some states provided specific requests regarding representative counties. Following the reanalysis and state requests, 315 representative counties were selected for the 2016v1 platforms and those representative counties were retained for this analysis. More details on the methodology behind choosing representative counties is available in the 2016v1 TSD.

Emission factors were generated by running MOVES for each representative county for two "fuel months" – January to represent winter months and July to represent summer months – because in some parts of the country different types of fuels are used in each season. MOVES

[7] USEPA (2021). *Exhaust Emission Rates for Heavy-Duty Onroad Vehicles in MOVES_CTI_NPRM.* Attachment to a Memorandum to Docket EPA-HQ-OAR-2019-0055. Updates to MOVES for Emissions Analysis of the Cleaner Trucks Initiative NPRM. Docket ID EPA-HQ-OAR-2019-0055. May 2021.

was run for the range of temperatures that occur in each representative county for each season. The calculations of the temperature ranges needed for each fuel month were based on meteorology for every county and grid cell in the continental U.S. for each hour of the year. The SMOKE interface accounts for the sensitivity of the on-road emissions to temperature and humidity by using the gridded hourly temperature information available from the meteorological model outputs used for air quality modeling.

MOVES_CTI_NPRM was run using the above approach to create emission factors for each of the three modeling cases: 2016 base year, 2045 reference, and 2045 control. A new set of emission factor tables were developed for this study using the same representative counties as were used the 2016v1 platform. The county databases (CDBs) input to MOVES for 2016 were equivalent to those used for the 2016v1 platform but were updated to include the new tables needed by MOVES_CTI_NPRM. To prepare the 2045 CDBs used to generate year 2045 emissions factors, the age distributions were projected to reflect the year 2045 as were the tables representing the inspection and maintenance programs. The fuels used were also representative of year 2045. In addition to the emission factors tables output from MOVES 2014b, the tables for this study include emission factors for off-network idling (ONI), which was not part of the 2016v1 platform.

3.2 Activity Data Development

To compute onroad mobile source emissions, SMOKE selects the appropriate MOVES emissions rates for each county, hourly temperature, speed bin, and SCC (which includes the fuel type, source type and road type), then multiplies the emission rate by appropriate activity data such as VMT (vehicle miles travelled), VPOP (vehicle population), or HOTELING (hours of extended idle) to produce emissions. MOVES_CTI_NPRM also required off-network idling hours activity data that were not needed by MOVES2014b. For each of these activity datasets, first a national dataset was developed; this national dataset is called the “EPA default” dataset. Data submitted by state agencies were incorporated into the activity data sets used for the study where they were available and passed quality assurance checks.

The activity data for the 2016 base year were consistent with the activity data used in the 2016v1 platform, except for off-network idling hours, which is a new type of activity data needed by MOVES_CTI_NPRM. Additional details on the development of activity data other than off-network idling are available in the 2016v1 TSD.

3.2.1 2016 Base Year Activity data

3.2.1.1 2016 VMT

EPA calculated default 2016 VMT by projecting the 2014 National Emissions Inventory (NEI) version 2 (v2) platform VMT to 2016. The *2014NEIv2 Technical Support Document* has details on the development of those VMT. The data projected to 2016 were used for states that did not submit 2016 VMT data. Projection factors to grow state VMT from *2014* to *2016* were based on state-level VMT data from the Federal Highway Administration (FHWA) VM-2 reports. For most states, separate factors were calculated for urban VMT and rural VMT. Some states have a very different distribution of urban activity versus rural activity between 2014NEIv2 and the FHWA data, due to inconsistencies in the definition of urban versus rural. For those states, a single state-wide projection factor based on total FHWA VMT across all road types was applied to all VMT independent of road type. The following states used a single state-wide projection factor to adjust the VMT to 2016 levels: AK, GA, IN, ME, MA, NE, NM, NY, ND, TN, and WV. Also, state-wide projection factors in Texas and Utah were developed from alternative VMT datasets provided by their respective Departments of Transportation.

For the 2016v1 platform, VMT data submitted by state and local agencies were incorporated and used in place of EPA defaults, as described below. Note that VMT data need to be provided to SMOKE for each county and SCC. The onroad SCCs characterize vehicles by MOVES fuel type, vehicle (aka source) type, emissions process, and road type. Any VMT provided at a different resolution than this were converted to a full county-SCC resolution to prepare the data for processing by SMOKE.

A final step was performed on all state-submitted VMT. The distinction between a "passenger car" (MOVES source type 21) versus a "passenger truck" (MOVES source type 31) versus a "light commercial truck" (MOVES source type 32) is not always consistent between different datasets. This distinction can have a noticeable effect on the resulting emissions, since MOVES emission factors for passenger cars are quite different than those for passenger trucks and light commercial trucks.

To ensure consistency in the 21/31/32 splits across the country, all state-submitted VMT for MOVES vehicle types 21, 31, and 32 (all of which are part of HPMS vehicle type 25) was summed, and then re-split using the 21/31/32 splits from the EPA default VMT which use a consistent data source for all states. VMT for each source type as a percentage of total 21/31/32 VMT was calculated by county from the EPA default VMT. Then, state-submitted VMT for 21/31/32 was summed and re-split according to those percentages.

3.2.1.2 2016 VPOP

The EPA default VPOP dataset was based on the EPA default VMT dataset described above. For each county, fuel type, and vehicle type, a VMT/VPOP ratio (miles per vehicle per year) was calculated based on the 2014NEIv2 VMT and VPOP datasets. That ratio was applied to the 2016 EPA default VMT, to produce an EPA default VPOP projection.

Several state and local agencies submitted VPOP data for the beta and v1 platforms, and those data were used in place of the EPA default VPOP once converted to the appropriate level of detail needed by SMOKE. EPA default VPOP data were used for the states that submitted VMT but did not submit VPOP. VPOP by source type was not re-split among the LD types 21/31/32 in the same way that the VMT was split.

3.2.1.3 2016 Speed (Distributions and Average)

In the version of SMOKE used for this analysis (SMOKE 4.7), SMOKE-MOVES was updated to use speed distributions similarly to how they are used when running MOVES in inventory mode. This new speed distribution file, called SPDIST, specifies the amount of time spent in each

MOVES speed bin for each county, vehicle (aka source) type, road type, weekday/weekend, and hour of day. This file contains the same information at the same resolution as the Speed Distribution table used by MOVES but is reformatted for SMOKE. Using the SPDIST file results in a SMOKE emissions calculation that is more consistent with MOVES than the old hourly speed profile (SPDPRO) approach, because emission factors from all speed bins can be used, rather than interpolating between the two bins surrounding the single average speed value for each hour as is done with the SPDPRO approach.

As was the case with the previous SPDPRO approach, the SPEED inventory that includes a single overall average speed for each county, SCC, and month, must still be read in by the SMOKE program Smkinven. SMOKE requires the SPEED dataset to exist even when speed distribution data are available, even though only the speed distribution data affects the selection of emission factors. The SPEED dataset is carried over from 2014NEIv2, while the SPDIST dataset is new for the 2016v1 platform. Both are based on a combination of the Coordinating Research Council (CRC) A-100 data and MOVES CDBs.

3.2.1.4 2016 Hoteling hours

Hoteling hours activity is used to calculate emissions from extended idling and auxiliary power units (APUs) for heavy duty diesel vehicles. For the 2016v1 platform, hoteling hours were recomputed using a new factor identified by EPA's Office of Transportation and Air Quality as more appropriate based on recent studies.

The method used in 2016v1 is the following:

1 Start with 2016v1 VMT for combination long haul trucks (i.e., MOVES source type 62) on restricted roads, by county.
2 Multiply the VMT by 0.007248 hours/mile.[8] This results in about 73.5% less hoteling hours as compared to the approach for the 2014v2 NEI.
3 Apply parking space reductions in counties where the number of known parking spaces does not support the number of hoteling hours assigned.

Hoteling hours were adjusted down in counties for which there were more hoteling hours assigned to the county than could be supported by the known parking spaces. To compute the adjustment, the hoteling hours for the county were computed using the above method, and reductions were applied directly to the 2016 hoteling hours based on known parking space availability so that there were not more hours assigned to the county than the available parking spaces could support if they were full every hour of every day.

A dataset of truck stop parking space availability with the total number of parking spaces per county was used in the computation of the adjustment factors. [9] This same dataset is used to

[8] USEPA (2020). *Population and Activity of Onroad Vehicles in MOVES3*. EPA-420-R-20-023. Office of Transportation and Air Quality. US Environmental Protection Agency. Ann Arbor, MI. November 2020. https://www.epa.gov/moves/moves-technical-reports.
[9] From *2016 version 1 hoteling workbook.xlsx* developed based on the input dataset for the hoteling spatial surrogate in the 2016v1 platform.

develop the spatial surrogate for hoteling emissions. Since there are 8,784 hours in the year 2016; the maximum number of possible hoteling hours in a particular county is equal to 8,784 * the number of parking spaces in that county. Hoteling hours for each county were capped at that theoretical maximum value for 2016 in that county unless the number of parking spaces listed was less than 12, in which case the hours were not reduced.

3.2.1.5 Off-Network Idling

In MOVES, overnight idling by long haul combination trucks is accounted for as the extended idling fraction of hoteling activity. Idling is also estimated in MOVES as the portion of driving schedules where the speed is zero, and this idling activity is incorporated in the rate per distance emission rates associated with VMT activity in SMOKE-MOVES.

MOVES driving schedules do not include idling that occurs in parking lots, driveways, or during "workday" truck operation such as queuing at a distribution center, loading freight, etc. In MOVES_CTI_NPRM, we incorporated these additional idling activities and classify it as "Off-network idling (ONI)."

MOVES_CTI_NPRM calculates off-network idle (ONI) in inventory mode from:

- Total idle fraction: The fraction of total source hour operation that is idling (excluding extended idling). The total idle fraction is defined by source type, month, idle region, county type (urban/rural), month, and day type (weekday or weekend).
- On-network idling hours: The on-network idling is a function of average speed distributions, road type distributions, and the idle that occurs in the MOVES drive cycles.

Where total idling hours = on-network idling hours + off-network idling hours. ONI is calculated as the difference between the total idling hours and the on-network idling hours. The total idle fractions in MOVES_CTI_NPRM are estimated from instrumented vehicle data from the Verizon Telematics Database for the light-duty vehicles and the National Renewable Energy Laboratory's FleetDNA Database for the heavy-duty vehicles. Both these datasets suggest that the fraction of idling hours is higher than what is estimated in MOVES from the on-network driving cycles.[10]

For conducting SMOKE-MOVES runs, we needed to provide ONI activity as an input, rather than have it be calculated during the inventory run. We used the following steps to calculate ONI activity for each county, source type, and month.

We first calculated the source hours operating (SHO) for each county by source type, road type and month using Equation 1. We calculated an average speed from the SPDIST dataset documented above, and we used the 2016 NEI VMT.

[10] USEPA (2021). *Population and Activity of Onroad Vehicles in MOVES_CTI_NPRM*. Attachment to a Memorandum to Docket EPA-HQ-OAR-2019-0055. Updates to MOVES for Emissions Analysis of the Cleaner Trucks Initiative NPRM. Docket ID EPA-HQ-OAR-2019-0055. May 2021.

$$SHO_{county,s,r,m} = \frac{VMT_{county,s,r,m}}{average\ speed_{county,s,r,m}} \qquad \textbf{Equation 1}$$

Where: s= sourceTypeID
r= roadTypeID
m= monthTypeID

We then aggregate the SHO from roadtypes 2, 3, 4 and 5 to calculate the total on-network SHO ($SHO_{roadtypeID2\text{-}5}$) for each county, source type, and month.

We then estimated the amount of ONI activity that occurs in different counties with respect to the on-network SHO using parameter called the ONI fraction. The ONI fraction is defined in Equation 2, and is calculated for each idleregionID (i), countyTypeID (c), sourcetypeID (s), and monthID (m).

$$ONI\ fraction_{i,c,s,m} = \frac{ONI_{i,c,s,m}}{\sum_{r=2}^{5} SHO_{i,c,s,r,m}} \qquad \textbf{Equation 2}$$

Where: $ONI_{i,c,s,m,}$ *= off-network idling hours, calculated from MOVES as the source hours operating on roadtype 1 (off-network)*
$SHO_{i,c,s,m,r\in(2,3,4,5)}$ *= source hours operating for on-network roadtypes (roadtypeID 2,3,4 and 5)*
i = idleregionID (101,102,103,104,105)
c= countyTypeID (rural = 0, urban=1)

We estimated the ONI fraction from MOVES county-level inventory runs conducted for a rural and an urban county from each idle region.[11] We use MOVES defaults inputs except for the road type distribution, source type population, and VMT. Source type population and VMT are kept constant across the representative counties using values of 1000 vehicles and 1000 miles per year for each source type.[12] The road type VMT distribution was calculated for the representative idle region counties using the total VMT by source type from the 2016 version 1. Again, these counties represent the whole idle region and not just the individual county. For example, the road type VMT distribution for Atlantic County, NJ is updated to reflect the road type VMT

[11] The exact urban or rural county we select does not matter for the ONI calculations for two reasons. 1. We are updating the VMT road type fractions to be representative of the entire idle region and county type. 2. The other default MOVES inputs that influence ONI at inventory mode (average speed distribution, VMT by hour of the day, VMT by day of the week are the same for all US counties.

[12] We are only interested in the relative amount of ONI to source hours operating, so the magnitude of the vehicle population of VMT is inconsequential.

distribution for the VMT that occurs in all urban counties in the Northeast Idle Region (Idle region 101). Table 3-1 contains the "representative idle region" counties chosen to represent the urban and rural counties within each idle region.

Table 3-1 Ten representative idle region counties

Idle Region	County Type	Name of the county
101	Urban	Atlantic County, NJ 34001
101	Rural	Addison county, Vermont, 50001
102	Urban	Aransas County, Corpus Christi, TX, 48007
102	Rural	Alleghany county, NC, 37005
103	Urban	Cook county, Illinois, 17031
103	Rural	Alcona county, MI, 26001
104	Urban	Adams county, CO, 8001
104	Rural	Albany county, WY, 56001
105	Urban	Asotin county, WA, 53003
105	Rural	Churchill county, NV, 32001

We then estimated the ONI hours in each county, source type and month, by multiplying the on-network SHO for each county, source type, and month, by the representative ONI fraction for that idle region, county type, source type and month using Equation 3.

$$ONI_{county,s,m} = \sum_{r=2}^{5} \left(SHO_{county,s,r,m}\right) \times ONI\ fraction_{i,c,s,m} \qquad \textbf{Equation 3}$$

$Where:\ county \in (idleregion\ i\ \&\ countyTypeID\ c\ )$

The ONI activity data were placed in a new ONI FF10 table, which includes estimates of ONI hours by the SMOKE-MOVES Source Classification Code (SCC), (defined by source type, fuel type, and road type=01) for each month and county in the lower 48 states.

3.2.1.6 Fuels

The 2016 MOVES_CTI_NPRM fuel supply was derived from the fuel supply used in the 2016 version 1 (2016v1) Air Emissions Modeling Platform.[13] The 2016v1 fuel supply was created from the MOVES2014b fuel supply but updated to account for new data. It also simplified the handling of biofuels by setting all non-E85 gasoline to E10 nationwide (no E15 or E0) and set all diesel nationwide at B5 biodiesel. Other fuel properties such as sulfur, aromatics, and Reid

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[13] USEPA (2021). *Technical Support Document (TSD) Preparation of Emissions Inventories for the 2016v1 North American Emissions Modeling Platform*. U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. Air Quality Assessment Division. Emissions Inventory and Analysis Group. Research Triangle Park, North Carolina. March 2021. https://www.epa.gov/air-emissions-modeling/2016-version-1-technical-support-document.

Vapor Pressure (RVP) were based on 2015 and 2016 calendar year gasoline production data submitted to EPA's fuel compliance system, processed and analyzed in the same way as described in the MOVES2014 Fuel Supply Report.[14]

For the 2045 future-year scenarios, gasoline sulfur was adjusted downward to account for full phase-in of the Tier 3 gasoline standard of 10 ppm.[15] The gasoline aromatics levels were lowered slightly to account for the desulfurization processes used to implement the Tier 3 sulfur level (specifically, 0.032 vol% aromatics reduction per ppm sulfur reduction) based on the refinery modeling done for the Tier 3 program. This factor is shown in Table 4 of the MOVES2014b Fuel Supply Defaults technical report.[14] No other changes to fuel properties were made from the 2016 base case, including maintaining the same levels of E10, E85, and biodiesel. No changes were made to California because the gasoline sulfur level was already below 10 ppm in the base case.

In addition to the fuel formulation adjustments described above, some updates were made to the mapping of counties into fuel property regions to reflect changes to local fuel regulations. The 2016 scenario used here differs from the 2016v1 platform version in two places:

- In Georgia there was historically a 45-county region around Atlanta that had 7.0 psi fuel. Starting in summer 2014, this changed to 7.8 psi in a smaller, 13-county area, and the other 32 counties reverted to 9 psi conventional gasoline. The 2016v1 platform database still showed the larger 7.0 psi region, so a correction was made for the CTI_NPRM fuel supply. [16,17]
- In Tennessee, the 2016v1 platform was missing the five-county 7.8 psi area around Nashville, which remained in effect through the end of summer 2017. Therefore, 2016 calendar year CTI_NPRM fuel supply was adjusted to include this 7.8 psi control area.[18]

Additional changes for the future-year scenarios were made as follows:

- In Tennessee, the five counties mentioned above plus a sixth county (Shelby) reverted to 9.0 psi conventional gasoline in 2017 and 2018.[19]

[14] USEPA (2018). *Fuel Supply Defaults: Regional Fuels and the Fuel Wizard in MOVES2014b*. EPA-420-R-18-008. Office of Transportation and Air Quality. US Environmental Protection Agency. Ann Arbor, MI. July 2018. https://www.epa.gov/moves/moves-technical-reports.

[15] USEPA (2014). Tier 3 Vehicle Emission and Fuel Standards Program. Regulatory Impact Analysis. EPA-420-R-14-004. February 2014. http://www.epa.gov/otaq/tier3.htm.

[16] USEPA (2019). *Proposed Relaxation of the Federal Reid Vapor Pressure (RVP) Gasoline Volatility Standard for the Atlanta RVP Area.* EPA-420-F-19-039. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100WNXT.pdf.

[17] USEPA (2014) *Regulation of Fuel and Fuel Additives: Reformulated Gasoline Requirements for the Atlanta Covered Area.* 79 FR 14410, March 14, 2014. https://www.govinfo.gov/content/pkg/FR-2014-03-14/pdf/2014-05697.pdf.

[18] USEPA (2017). *Approval of Tennessee's Request to Relax the Federal Reid Vapor Pressure Gasoline Volatility Standard for Davidson, Rutherford, Sumner, Williamson, and Wilson Counties; and Minor Technical Corrections for Federal Reid Vapor Pressure Gasoline Volatility Standards in Other Areas.* 82 FR 26354. https://www.govinfo.gov/content/pkg/FR-2017-06-07/pdf/2017-11700.pdf.

[19] USEPA (2017). *Approval of Tennessee's Request to Relax the Federal Reid Vapor Pressure (RVP) Gasoline Volatility Standard for Shelby County (Memphis).* 82 FR 60675. https://www.govinfo.gov/content/pkg/FR-2017-12-22/pdf/2017-27630.pdf.

- In Louisiana, sixteen parishes around the New Orleans area reverted to 9.0 psi conventional gasoline in 2018 and 2019.[20,21]

The local RVP limits described above are for E0; for the MOVES_CTI_NPRM fuel supply where all gasoline is assumed to be E10, 1 psi was added to these RVP values to account for the effect of ethanol blending.

In May 2019, there was a proposed rule to move the Atlanta metro area to 9 psi RVP. Because it was not finalized at the time of this analysis, we kept the Atlanta area at 7.8 psi in the MOVES_CTI_NPRM fuel supply.

3.2.2 2045 Projected Activity Data

To compute 2045 emissions for the onroad sector, VMT, VPOP, hoteling and off-network idling activity data were projected from 2016 to 2045. MOVES was then run to compute emission factors for 2045.

For the 2016v1 platform, VMT, VPOP, and hoteling activity data were projected to 2028, and these data sets incorporated locally submitted data for 2028. These 2028 projections were used as the basis of the 2045 projections for this study. ONI activity is projected using the VMT growth factors and hoteling is projected based on combination long haul truck VMT growth. The development of the 2028 activity data is described in detail in the 2016v1 platform TSD. Both the 2045 reference and control scenarios use the same activity data.

3.2.2.1 2045 VMT

As in the 2016v1 platform, annual VMT data from the Annual Energy Outlook (AEO) 2019 reference case were used to calculate national projection factors for VMT by fuel and vehicle type. Specifically, the following two AEO2019 tables were used:

- Light Duty (LD): Light-Duty VMT by Technology Type (table #51)
- Heavy Duty (HD): Freight Transportation Energy Use (table #58)

Additional details on the projection procedure are in the 2016v1 platform TSD. The projection procedure for this study is the same, except the projections are based on AEO2019 data for 2028 and 2045 only. The 2028-to-2045-year VMT projection factors are provided in Table 3-2.

Table 3-2 Factors to Project 2028 VMT to 2045

SCC6	description	2045 factor
220111	LD gas	2.48%

[20] USEPA (2017). *Approval of Louisiana's Request To Relax the Federal Reid Vapor Pressure (RVP) Gasoline Volatility Standard for Several Parishes.* 82 FR 60886. https://www.govinfo.gov/content/pkg/FR-2017-12-26/pdf/2017-27628.pdf.

[21] USEPA (2018). *Approval of Louisiana's Request To Relax the Federal Reid Vapor Pressure (RVP) Gasoline Standard for the Baton Rouge Area.* 83 FR 53584. https://www.govinfo.gov/content/pkg/FR-2018-10-24/pdf/2018-23247.pdf.

SCC6	description	2045 factor
220121	LD gas	2.48%
220131	LD gas	2.48%
220132	LD gas	2.48%
220142	Buses gas	55.16%
220143	Buses gas	55.16%
220151	MHD gas	55.16%
220152	MHD gas	55.16%
220153	MHD gas	55.16%
220154	MHD gas	55.16%
220161	HHD gas	-18.08%
220221	LD diesel	62.01%
220231	LD diesel	62.01%
220232	LD diesel	62.01%
220241	Buses diesel	17.00%
220242	Buses diesel	17.00%
220243	Buses diesel	17.00%
220251	MHD diesel	17.00%
220252	MHD diesel	17.00%
220253	MHD diesel	17.00%
220254	MHD diesel	17.00%
220261	HHD diesel	8.15%
220262	HHD diesel	8.15%
220342	Buses CNG	259.12%
220521	LD E-85	-2.13%
220531	LD E-85	-2.13%
220532	LD E-85	-2.13%
220921	LD Electric	184.07%
220931	LD Electric	184.07%
220932	LD Electric	184.07%

In addition, projected human population data for 2028 and 2045 was used to provide spatial variability in the projected VMT for light duty vehicles. Additional details on this procedure are in the 2016v1 TSD.

For the year 2045, additional considerations were made for fuels and vehicle types which are phased out by the MOVES model that far into the future. For example, in the year 2045, MOVES no longer generates emission factors for gasoline combination short-haul vehicles (SCCs starting with 220161). In the state of New York, MOVES also sometimes does not generate emission factors for gasoline single unit long-haul vehicles (SCCs starting in 220153). Therefore, there should not be VMT data for those SCCs in 2045. To account for this, after creating the projected 2045 VMT, all gasoline combination short-haul VMT was moved to diesel combination short-haul SCCs (220261). Similarly, in New York, all gasoline single unit long-haul VMT was moved to gasoline single unit short-haul SCCs (220152).

3.2.2.2 2045 VPOP, Hoteling hours, and Off-network Idling (ONI)

To project VPOP to 2045, VMT/VPOP ratios for each county, fuel, and vehicle type were calculated from the 2028 VMT and VPOP data. Those ratios were then applied to the 2045 projected VMT to estimate 2045 VPOP.

Similarly, for hoteling hours, 2028 inventory HOTELING/VMT ratios were calculated for each county for combination long-haul trucks on restricted roads only, and then applied to the 2045 projected VMT to estimate 2045 hoteling hours. For hoteling, each future year also has a distinct percentage of hours for which auxiliary power units (APUs) are assumed to be used based on the MOVES input data used to split county total hoteling to each SCC. For 2045, 31.6% of all hoteling activity is assigned to the APU process.

For ONI, a 2028 projection was not already available, and so we could not calculate 2028 VMT/ONI ratios to estimate 2045 ONI activity. Instead, VMT/ONI ratios were calculated from 2016 activity for each county, fuel, and vehicle type, and then applied to the 2045 projected ONI to estimate 2045 ONI.

3.3 Onroad Emissions Modeling

The SMOKE-MOVES process for creating the air quality model-ready onroad mobile emissions consists of the following steps:

1) Select the representative counties to use in the MOVES runs.
2) Determine which months will be used to represent other month’s fuel characteristics.
3) Create inputs needed only by MOVES. MOVES requires county-specific information on vehicle populations, age distributions, speed distribution, road type distributions, temporal profiles, inspection-maintenance programs, and presence of Low Emission Vehicle (LEV) program for each of the representative counties.
4) Create inputs needed both by MOVES and by SMOKE, including temperatures and activity data.
5) Run MOVES to create emission factor tables for the temperatures and speeds that exist in each county during the modeled period.
6) Run SMOKE to apply the emission factors to activity data (VMT, VPOP, HOTELING, ONI) to calculate emissions based on the gridded hourly temperatures in the meteorological data.
7) Aggregate the results to the county-SCC level for summaries and QA.

The onroad emissions are processed as five components that are merged into the final onroad sector emissions:

- rate-per-distance (RPD) uses VMT as the activity data plus speed and speed profile information to compute on-network emissions from exhaust, evaporative, permeation, refueling, and brake and tire wear processes;
- rate-per-vehicle (RPV) uses VPOP activity data to compute off-network emissions from exhaust, evaporative, and permeation processes;
- rate-per-profile (RPP) uses VPOP activity data to compute off-network emissions from evaporative fuel vapor venting, including hot soak (immediately after a trip) and diurnal (vehicle parked for a long period) emissions;
- rate-per-hour (RPH) uses hoteling hours activity data to compute off-network emissions for idling of long-haul trucks from extended idling and auxiliary power unit process; and
- rate-per-hour-ONI (RPHO) uses off-network idling hours activity data to compute emissions for vehicles while idling off-network, (e.g., idling in a parking lot or unloading freight). This is a new emission calculation which was added to the CTI version of MOVES.

One difference affecting the RPV rate between the MOVES_CTI_NPRM model and other versions of MOVES (e.g., MOVES2014b) is that the RPV rate no longer includes refueling emissions from the fuel consumption from vehicle starts (nor from the additional off-network idling). The impact on total refueling emissions is minor because on-network driving consumes the vast majority of fuel consumption in contrast to starts and ONI. Also, a side effect of how MOVES_CTI_NPRM is run is that emission factor tables for RPV and RPP include records pertaining to RPD processes. Those RPD records are removed from the RPV emission factor tables prior to running SMOKE-MOVES. They do not need to be removed from the RPP tables because their presence does not affect RPP processing.

As described above, MOVES_CTI_NPRM was run for three scenarios: 2016, a 2045 reference case, and a 2045 control case. The 2045 reference and control cases use different MOVES emission factor tables, but otherwise share all the same inputs, including activity data and ancillary files.

California submitted their own onroad emissions for use in the 2016v1 modeling platform, but throughout this study, MOVES was exclusively used to compute onroad emissions in California. Therefore, none of the procedures used to incorporate California-submitted onroad emissions data into the 2016v1 were needed for this study.

SCC descriptions for onroad emissions

SCCs in the onroad sector follow the pattern 220**FVV**0**RPP**, where:

- F = MOVES fuel type (1 for gasoline, 2 for diesel, 3 for CNG, 5 for E-85, and 9 for electric)
- VV = MOVES vehicle (aka source) type, see Table 3-3

- R = MOVES road type (1 for off-network, 2 for rural restricted, 3 for rural unrestricted, 4 for urban restricted, 5 for urban unrestricted)
- PP = SMOKE aggregate process. In the activity data, the last two digits of the SCC are always 00, because activity data is process independent. MOVES separately tracks over a dozen processes, but for computational reasons it is not practical to model all of these processes separately within SMOKE-MOVES. Instead, "aggregate" processes are used in SMOKE. To support this, the MOVES processes are mapped to SMOKE aggregate processes according to Table 3-4. The MOVES_CTI_NPRM model includes a new process, 92, corresponding to emissions from on-network idling (ONI).

Table 3-3 MOVES vehicle types

MOVES Vehicle Type	Description
11	Motorcycle
21	Passenger Car
31	Passenger Truck
32	Light Commercial Truck
41	Intercity Bus
42	Transit Bus
43	School Bus
51	Refuse Truck
52	Single Unit Short-haul Truck
53	Single Unit Long-haul Truck
54	Motor Home
61	Combination Short-haul Truck
62	Combination Long-haul Truck

Table 3-4 SMOKE-MOVES aggregate processes

MOVES Process ID	Process description	SMOKE aggregate process
01	Running Exhaust	72
02	Start Exhaust	72
09	Brakewear	40
10	Tirewear	40
11	Evap Permeation	72
12	Evap Fuel Vapor Venting	72
13	Evap Fuel Leaks	72
15	Crankcase Running Exhaust	72
16	Crankcase Start Exhaust	72
17	Crankcase Extended Idle Exhaust	53
18	Refueling Displacement Vapor Loss	62
19	Refueling Spillage Loss	62
90	Extended Idle Exhaust	53
91	Auxiliary Power Exhaust	91
92	On-network Idle Exhaust	92

3.3.1 Spatial Surrogates

Onroad county activity data were allocated to a national 12 km grid for air quality modeling using spatial surrogates. For all processes other than the new ONI process present in the MOVES_CTI_NPRM model, the spatial surrogates used to allocate onroad activity to the national 12km grid are the same as in the 2016v1 platform and are described in the 2016v1 platform TSD. ONI activity was spatially allocated using the surrogates listed in Table 3-5. These are the same surrogates that are used to spatially allocate VPOP activity for off-network emissions.

Table 3-5 Spatial surrogates for on-network idling (ONI)

Source Type	Description	Spatial Surrogate	Description
11	Motorcycle	307	NLCD All Development
21	Passenger Car	307	NLCD All Development
31	Passenger Truck	307	NLCD All Development
32	Light Commercial Truck	308	NLCD Low + Med + High
41	Intercity Bus	258	Intercity Bus Terminals
42	Transit Bus	259	Transit Bus Terminals
43	School Bus	506	Education
51	Refuse Truck	306	NLCD Med + High
52	Single Unit Short-haul Truck	306	NLCD Med + High
53	Single Unit Long-haul Truck	306	NLCD Med + High
54	Motor Home	304	NLCD Open + Low
61	Combination Short-haul Truck	306	NLCD Med + High
62	Combination Long-haul Truck	306	NLCD Med + High

3.3.2 Temporal Profiles

For on-network and hoteling emissions, VMT and hoteling activity were temporalized from annual or monthly values to hourly and SMOKE was run for every day of the year. The temporal profiles for VMT and hoteling activity are the same as in the 2016v1 platform and are described in more detail in the 2016v1 platform TSD. For MOVES_CTI_NPRM modeling, ONI monthly activity data were temporalized to hourly using a subset of the temporal profiles that are used to temporalize VMT. VMT data are temporalized using temporal profiles which vary by region (e.g., county, MSA), source type, and road type. ONI activity does specify regions and source types, but not road types. This means ONI cannot be temporalized in the same exact way as VMT. Instead, a subset of the VMT temporal profiles was selected to be applied to ONI. Only temporal profiles for unrestricted road types were chosen to be used for ONI, since off-network idling activity is assumed to better match the temporal pattern of unrestricted road type driving, rather than on freeways. There are also different VMT temporal profiles for urban road types and rural road types. ONI activity has no urban or rural designation, and so within each county, we can only apply either a rural temporal profile or an urban temporal profile. Therefore, we used the MOVES_CTI_NPRM county classification as either an urban county or a rural county for the purposes of choosing appropriate temporal profiles for ONI in each county.[22] In urban counties, ONI activity was temporalized using VMT profiles for urban unrestricted roads, and in rural counties, ONI activity was temporalized using VMT profiles for rural unrestricted roads.

3.3.3 Chemical Speciation

Chemical speciation of onroad emissions is internal to MOVES except for brake and tire-wear particulate matter (PM) speciation, which occurs in SMOKE. The emission factor tables from MOVES include both unspeciated emissions totals in grams for criteria air pollutants (CAPs) and hazardous air pollutants (HAPs), and speciated emissions totals for CB6 model species in moles (or grams for PM). The speciation cross reference (GSREF) and speciation profile (GSPRO) input files used by SMOKE-MOVES do not do any actual speciation. The GSREF file has no function and only exists to prevent a SMOKE error. The GSPRO and mobile emissions process and pollutant (MEPROC) files in SMOKE work in tandem to select which species and pollutants to include in SMOKE outputs. The MEPROC includes all unspeciated pollutants, and the GSPRO maps unspeciated pollutants to individual model species (e.g., brake wear PM2_5 to all individual PM species). Model-ready emissions files will include all species in the GSPRO that are mapped to one or more pollutants present in the MEPROC. Movesmrg reports include all of those model species, plus all of the pollutants listed in the MEPROC.

[22] USEPA (2020). *Population and Activity of On-road Vehicles in MOVES CTI NPRM*. Office of Transportation and Air Quality. US Environmental Protection Agency. Ann Arbor, MI.

3.3.4 Other Ancillary Files

SMOKE-MOVES requires several other types of ancillary files to prepare emissions for air quality modeling:

- Mobile county cross reference (MCXREF): Maps individual counties to representative counties.
- Mobile fuel month cross reference (MFMREF): Maps actual months to fuel months for each representative county. May through September are mapped to the July fuel month, and all other months to the January fuel month.
- MOVES lookup table list (MRCLIST): Lists emission factor table filenames for each representative county.
- Mobile emissions processes and pollutants (MEPROC): Lists which pollutants to include in the SMOKE run.
- Meteorological data for MOVES (METMOVES): Gridded daily minimum and maximum temperature data. This file is created by the SMOKE program Met4moves and is used for RatePerProfile (RPP) processing.

4 Onroad and Nonroad Inventory Summary Tables

This section includes tables of onroad and nonroad emissions used in this analysis.

Table 4-1 Onroad NOx Emissions (short tons)

Onroad NOx	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Total (48 State)	3,475,869	930,693	483,257	2,545,176	73%	-447,436	-48%
Gasoline	1,671,609	102,923	100,788	1,568,686	94%	-2,135	-2%
Diesel	1,802,275	823,645	378,344	978,630	54%	-445,301	-54%
E85	744	83	83	661	89%	0	0%
CNG	1,241	4,042	4,041	-2,801	-226%	0	0%
Alabama	95,781	22,246	11,385	73,535	77%	-10,861	-49%
Arizona	75,089	17,101	9,767	57,988	77%	-7,334	-43%
Arkansas	55,266	14,545	7,001	40,721	74%	-7,544	-52%
California	264,402	83,871	44,452	180,531	68%	-39,419	-47%
Colorado	57,950	12,864	8,097	45,086	78%	-4,768	-37%
Connecticut	18,088	3,473	2,109	14,614	81%	-1,364	-39%
D.C.	3,086	887	550	2,198	71%	-337	-38%
Delaware	8,081	1,918	1,107	6,164	76%	-810	-42%
Florida	188,157	48,594	26,147	139,563	74%	-22,447	-46%
Georgia	147,938	34,910	16,977	113,027	76%	-17,933	-51%
Idaho	34,783	9,244	5,331	25,539	73%	-3,913	-42%
Illinois	111,305	34,659	16,486	76,646	69%	-18,172	-52%
Indiana	100,722	28,812	13,598	71,910	71%	-15,214	-53%
Iowa	49,107	11,850	5,968	37,257	76%	-5,882	-50%
Kansas	50,390	11,915	6,109	38,474	76%	-5,806	-49%
Kentucky	70,354	17,560	9,142	52,794	75%	-8,418	-48%
Louisiana	68,072	20,557	10,444	47,515	70%	-10,113	-49%
Maine	15,404	4,613	2,353	10,791	70%	-2,260	-49%
Maryland	49,505	15,448	7,825	34,058	69%	-7,623	-49%
Massachusetts	39,169	13,629	6,733	25,540	65%	-6,897	-51%
Michigan	86,517	18,169	10,853	68,348	79%	-7,316	-40%
Minnesota	60,013	14,412	8,138	45,601	76%	-6,274	-44%
Mississippi	53,502	12,420	6,120	41,082	77%	-6,300	-51%
Missouri	106,059	30,561	14,225	75,498	71%	-16,337	-53%
Montana	27,901	6,723	4,068	21,178	76%	-2,655	-39%
Nebraska	33,365	8,175	4,229	25,190	75%	-3,946	-48%
Nevada	30,451	7,478	4,444	22,973	75%	-3,034	-41%
New Hampshire	10,874	2,994	1,713	7,881	72%	-1,281	-43%

Onroad NOx	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
New Jersey	62,340	15,146	8,184	47,194	76%	-6,963	-46%
New Mexico	55,416	14,777	7,714	40,639	73%	-7,063	-48%
New York	95,123	32,597	18,636	62,526	66%	-13,961	-43%
North Carolina	110,933	20,318	10,688	90,615	82%	-9,630	-47%
North Dakota	24,079	8,163	4,034	15,916	66%	-4,128	-51%
Ohio	112,664	28,081	14,213	84,583	75%	-13,868	-49%
Oklahoma	72,936	18,197	9,671	54,739	75%	-8,527	-47%
Oregon	50,404	11,812	7,145	38,592	77%	-4,667	-40%
Pennsylvania	116,013	34,951	17,338	81,062	70%	-17,614	-50%
Rhode Island	8,236	2,908	1,353	5,327	65%	-1,555	-53%
South Carolina	77,638	19,079	9,433	58,559	75%	-9,646	-51%
South Dakota	19,405	5,465	2,973	13,940	72%	-2,492	-46%
Tennessee	99,685	25,058	11,700	74,627	75%	-13,358	-53%
Texas	298,794	90,156	44,192	208,638	70%	-45,964	-51%
Utah	58,859	21,268	11,074	37,591	64%	-10,195	-48%
Vermont	4,848	1,434	864	3,413	70%	-570	-40%
Virginia	86,750	17,661	9,145	69,089	80%	-8,516	-48%
Washington	86,620	20,801	12,000	65,819	76%	-8,801	-42%
Virginia	27,886	7,292	3,651	20,595	74%	-3,640	-50%
Wisconsin	75,077	19,835	10,659	55,242	74%	-9,176	-46%
Wyoming	20,832	6,063	3,221	14,769	71%	-2,842	-47%

Table 4-2 Onroad $PM_{2.5}$ Emissions (short tons)

Onroad $PM_{2.5}$	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Total (48 State)	99,690	39,211	38,667	60,479	61%	-544	-1.4%
Gasoline	31,797	25,995	25,919	5,802	18%	-76	-0.3%
Diesel	67,836	13,085	12,618	54,751	81%	-468	-3.6%
E85	34	30	30	4	13%	0	0.0%
CNG	22	100	100	-78	-350%	0	0.0%
Alabama	2,491	862	849	1,629	65%	-13	-1.5%
Arizona	1,895	832	821	1,063	56%	-11	-1.3%
Arkansas	1,556	471	464	1,085	70%	-8	-1.6%
California	8,762	3,903	3,846	4,860	55%	-57	-1.5%
Colorado	1,495	724	719	771	52%	-4	-0.6%
Connecticut	480	243	242	237	49%	-1	-0.6%

Onroad $PM_{2.5}$	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
D.C.	128	76	76	51	40%	-1	-0.7%
Delaware	206	87	86	118	58%	-1	-1.2%
Florida	5,795	2,802	2,769	2,992	52%	-33	-1.2%
Georgia	3,935	1,503	1,481	2,431	62%	-22	-1.5%
Idaho	950	300	296	650	68%	-4	-1.5%
Illinois	3,352	1,508	1,487	1,845	55%	-21	-1.4%
Indiana	2,823	1,156	1,138	1,667	59%	-18	-1.6%
Iowa	1,311	468	462	843	64%	-6	-1.2%
Kansas	1,378	426	420	953	69%	-6	-1.4%
Kentucky	1,994	634	624	1,360	68%	-10	-1.6%
Louisiana	2,136	700	687	1,435	67%	-13	-1.9%
Maine	485	168	165	316	65%	-3	-1.7%
Maryland	1,553	636	627	917	59%	-9	-1.4%
Massachusetts	1,343	622	615	721	54%	-7	-1.2%
Michigan	2,324	1,162	1,151	1,162	50%	-11	-0.9%
Minnesota	1,607	725	717	881	55%	-8	-1.1%
Mississippi	1,396	457	449	939	67%	-8	-1.7%
Missouri	2,870	951	935	1,919	67%	-16	-1.7%
Montana	733	218	216	515	70%	-2	-1.1%
Nebraska	848	292	289	555	66%	-3	-1.2%
Nevada	813	404	401	409	50%	-3	-0.8%
New Hampshire	338	164	162	174	52%	-2	-1.3%
New Jersey	1,877	630	621	1,247	66%	-9	-1.4%
New Mexico	1,581	414	407	1,167	74%	-7	-1.7%
New York	3,713	1,481	1,454	2,232	60%	-27	-1.8%
North Carolina	2,667	1,244	1,234	1,424	53%	-9	-0.8%
North Dakota	795	192	188	603	76%	-4	-2.1%
Ohio	3,074	1,430	1,417	1,644	53%	-14	-0.9%
Oklahoma	2,042	677	665	1,365	67%	-12	-1.7%
Oregon	1,326	469	464	857	65%	-4	-0.9%
Pennsylvania	3,411	1,222	1,203	2,188	64%	-20	-1.6%
Rhode Island	272	98	97	174	64%	-2	-1.8%
South Carolina	2,042	665	655	1,377	67%	-10	-1.5%
South Dakota	570	155	153	415	73%	-2	-1.4%
Tennessee	2,490	980	968	1,510	61%	-12	-1.2%
Texas	8,650	3,380	3,325	5,270	61%	-55	-1.6%
Utah	1,847	624	610	1,223	66%	-14	-2.3%
Vermont	173	87	86	86	50%	-1	-0.9%
Virginia	2,138	952	943	1,186	55%	-9	-0.9%
Washington	2,264	855	844	1,409	62%	-11	-1.3%
Virginia	805	237	233	567	71%	-5	-1.9%
Wisconsin	2,390	770	759	1,620	68%	-11	-1.4%
Wyoming	565	152	150	412	73%	-2	-1.5%

Table 4-3 Onroad VOC Emissions (short tons)

Onroad VOC	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Total (48 State)	1,428,946	462,172	454,416	966,774	68%	-7,756	-1.7%
Gasoline	1,289,469	413,157	405,899	876,312	68%	-7,258	-1.8%
Diesel	138,152	45,252	44,754	92,901	67%	-497	-1.1%
E85	892	457	457	435	49%	0	0.0%
CNG	432	3,306	3,306	-2,873	-664%	0	0.0%
Alabama	43,092	11,280	11,081	31,812	74%	-199	-1.8%
Arizona	35,974	11,329	10,969	24,645	69%	-360	-3.2%
Arkansas	18,714	5,362	5,257	13,352	71%	-105	-2.0%
California	122,149	49,183	48,911	72,966	60%	-273	-0.6%
Colorado	28,224	9,587	9,533	18,637	66%	-54	-0.6%
Connecticut	10,250	3,737	3,729	6,513	64%	-9	-0.2%
D.C.	1,992	670	665	1,322	66%	-4	-0.7%
Delaware	4,261	1,600	1,581	2,661	62%	-19	-1.2%
Florida	91,858	30,785	30,298	61,073	66%	-487	-1.6%
Georgia	58,290	16,558	15,926	41,731	72%	-632	-3.8%
Idaho	12,965	3,971	3,889	8,994	69%	-82	-2.1%
Illinois	47,982	15,995	15,692	31,987	67%	-303	-1.9%
Indiana	40,662	12,489	12,323	28,173	69%	-166	-1.3%
Iowa	21,063	6,261	6,184	14,802	70%	-77	-1.2%
Kansas	19,458	5,548	5,480	13,909	71%	-68	-1.2%
Kentucky	26,893	7,629	7,527	19,263	72%	-103	-1.3%
Louisiana	24,691	7,481	7,359	17,209	70%	-123	-1.6%
Maine	5,545	2,184	2,141	3,361	61%	-43	-2.0%
Maryland	17,784	6,850	6,735	10,934	61%	-115	-1.7%
Massachusetts	17,544	6,919	6,866	10,625	61%	-53	-0.8%
Michigan	45,716	14,809	14,447	30,907	68%	-362	-2.4%
Minnesota	29,084	10,292	10,090	18,793	65%	-202	-2.0%
Mississippi	20,002	5,289	5,209	14,713	74%	-80	-1.5%
Missouri	38,772	11,328	11,196	27,444	71%	-132	-1.2%
Montana	11,439	3,477	3,449	7,962	70%	-28	-0.8%
Nebraska	14,124	3,987	3,947	10,138	72%	-40	-1.0%
Nevada	12,923	4,243	4,219	8,680	67%	-24	-0.6%
New Hampshire	5,096	2,090	2,048	3,006	59%	-42	-2.0%
New Jersey	23,051	8,166	8,041	14,885	65%	-125	-1.5%
New Mexico	15,931	4,987	4,915	10,944	69%	-72	-1.4%
New York	40,800	15,635	15,039	25,165	62%	-596	-3.8%
North Carolina	51,002	14,156	13,980	36,846	72%	-176	-1.2%
North Dakota	5,537	1,947	1,916	3,590	65%	-31	-1.6%
Ohio	55,392	16,594	16,395	38,798	70%	-199	-1.2%
Oklahoma	29,423	8,855	8,701	20,568	70%	-154	-1.7%
Oregon	23,434	6,673	6,629	16,760	72%	-44	-0.7%
Pennsylvania	45,643	16,171	15,696	29,472	65%	-475	-2.9%

Onroad VOC	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Rhode Island	3,198	1,177	1,161	2,021	63%	-17	-1.4%
South Carolina	30,706	8,697	8,597	22,008	72%	-100	-1.1%
South Dakota	6,912	2,283	2,262	4,629	67%	-21	-0.9%
Tennessee	39,877	11,030	10,854	28,847	72%	-176	-1.6%
Texas	94,213	28,846	28,135	65,367	69%	-711	-2.5%
Utah	17,561	6,964	6,866	10,597	60%	-98	-1.4%
Vermont	2,427	1,055	1,050	1,371	57%	-5	-0.5%
Virginia	36,956	11,305	11,215	25,652	69%	-90	-0.8%
Washington	39,473	12,377	12,188	27,095	69%	-189	-1.5%
Virginia	9,874	2,815	2,773	7,059	71%	-42	-1.5%
Wisconsin	25,462	9,810	9,572	15,652	61%	-238	-2.4%
Wyoming	5,528	1,694	1,678	3,834	69%	-15	-0.9%

Table 4-4 Onroad CO Emissions (short tons)

Onroad CO	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Total (48 State)	15,845,260	4,659,678	4,493,705	11,185,582	71%	-165,973	-3.6%
Gasoline	14,863,587	3,558,950	3,436,886	11,304,637	76%	-122,064	-3.4%
Diesel	962,383	1,013,240	969,332	-50,857	-5%	-43,909	-4.3%
E85	12,914	3,555	3,555	9,359	72%	0	0.0%
CNG	6,376	83,934	83,933	-77,557	-1216%	-1	0.0%
Alabama	481,693	111,944	108,794	369,749	77%	-3,150	-2.8%
Arizona	366,620	106,815	99,611	259,805	71%	-7,205	-6.7%
Arkansas	209,962	58,963	56,671	150,999	72%	-2,292	-3.9%
California	1,105,307	453,329	439,799	651,978	59%	-13,530	-3.0%
Colorado	289,771	79,317	78,276	210,453	73%	-1,042	-1.3%
Connecticut	112,026	32,038	31,602	79,988	71%	-437	-1.4%
D.C.	21,147	6,690	6,602	14,457	68%	-88	-1.3%
Delaware	47,326	14,716	13,968	32,610	69%	-748	-5.1%
Florida	1,142,314	315,475	309,509	826,839	72%	-5,966	-1.9%
Georgia	681,987	177,897	169,003	504,090	74%	-8,894	-5.0%
Idaho	127,342	35,462	34,033	91,880	72%	-1,428	-4.0%
Illinois	548,901	163,135	156,350	385,766	70%	-6,785	-4.2%
Indiana	474,594	128,551	125,235	346,043	73%	-3,316	-2.6%
Iowa	210,097	55,054	53,320	155,043	74%	-1,733	-3.1%
Kansas	202,655	53,054	51,617	149,601	74%	-1,437	-2.7%
Kentucky	307,221	80,074	77,403	227,147	74%	-2,671	-3.3%
Louisiana	281,271	82,350	80,123	198,920	71%	-2,227	-2.7%

Onroad CO	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Maine	59,804	23,405	22,007	36,399	61%	-1,397	-6.0%
Maryland	215,572	75,487	72,393	140,084	65%	-3,094	-4.1%
Massachusetts	190,046	70,737	68,667	119,309	63%	-2,071	-2.9%
Michigan	533,180	143,972	137,177	389,209	73%	-6,795	-4.7%
Minnesota	337,004	96,638	93,284	240,366	71%	-3,354	-3.5%
Mississippi	242,570	59,258	57,737	183,312	76%	-1,520	-2.6%
Missouri	428,723	121,071	117,331	307,652	72%	-3,741	-3.1%
Montana	110,325	28,474	27,825	81,851	74%	-649	-2.3%
Nebraska	139,462	35,316	34,407	104,146	75%	-909	-2.6%
Nevada	142,866	40,178	39,115	102,688	72%	-1,063	-2.6%
New Hampshire	58,837	20,279	19,088	38,558	66%	-1,191	-5.9%
New Jersey	264,326	87,069	82,632	177,257	67%	-4,438	-5.1%
New Mexico	161,164	51,913	50,376	109,251	68%	-1,536	-3.0%
New York	397,564	158,987	148,952	238,577	60%	-10,034	-6.3%
North Carolina	616,075	140,130	137,011	475,944	77%	-3,120	-2.2%
North Dakota	57,766	22,709	21,947	35,057	61%	-761	-3.4%
Ohio	632,791	154,954	150,549	477,836	76%	-4,405	-2.8%
Oklahoma	310,279	87,798	84,990	222,481	72%	-2,808	-3.2%
Oregon	225,412	52,756	51,671	172,656	77%	-1,085	-2.1%
Pennsylvania	476,491	180,672	170,535	295,819	62%	-10,137	-5.6%
Rhode Island	32,629	11,516	10,887	21,113	65%	-630	-5.5%
South Carolina	350,920	88,724	86,781	262,196	75%	-1,943	-2.2%
South Dakota	69,700	20,894	20,359	48,806	70%	-535	-2.6%
Tennessee	467,512	116,563	112,584	350,949	75%	-3,979	-3.4%
Texas	1,216,617	368,009	351,683	848,607	70%	-16,326	-4.4%
Utah	172,444	71,975	69,954	100,469	58%	-2,021	-2.8%
Vermont	25,018	9,867	9,611	15,150	61%	-256	-2.6%
Virginia	449,409	112,001	109,830	337,408	75%	-2,171	-1.9%
Washington	386,373	102,886	98,270	283,487	73%	-4,616	-4.5%
Virginia	109,317	30,582	29,607	78,735	72%	-975	-3.2%
Wisconsin	295,326	101,580	96,595	193,746	66%	-4,985	-4.9%
Wyoming	59,506	18,413	17,934	41,093	69%	-478	-2.6%

Table 4-5 Onroad Acetaldehyde Emissions (short tons)

Onroad Acetaldehyde	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Total (48 State)	14,551	4,081.1	4,046.2	10,470	72%	-34.9	-0.9%
Gasoline	9,725	2,201.9	2,187.7	7,523	77%	-14.1	-0.6%

Onroad Acetaldehyde	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Diesel	4,734	1,408.3	1,387.5	3,326	70%	-20.7	-1.5%
E85	55	15.8	15.8	39	71%	0	0.0%
CNG	36	455.2	455.2	-419	-1159%	0	0.0%
Alabama	376	64.0	63.3	312	83%	-0.7	-1.1%
Arizona	300	71.1	70.1	229	76%	-1	-1.4%
Arkansas	197	38.9	38.5	158	80%	-0.5	-1.2%
California	1,088	376.5	373.2	712	65%	-3.2	-0.9%
Colorado	278	97.6	97.3	181	65%	-0.3	-0.3%
Connecticut	101	34.3	34.2	67	66%	-0.1	-0.3%
D.C.	18	10.8	10.7	7	39%	0	-0.4%
Delaware	44	14.0	13.9	30	68%	-0.1	-0.6%
Florida	793	143.2	141.4	650	82%	-1.8	-1.2%
Georgia	559	128.8	127.2	430	77%	-1.6	-1.3%
Idaho	145	40.9	40.6	105	72%	-0.3	-0.8%
Illinois	538	190.5	189.0	347	65%	-1.5	-0.8%
Indiana	433	102.4	101.5	331	76%	-1	-0.9%
Iowa	223	57.4	57.0	165	74%	-0.3	-0.6%
Kansas	203	43.5	43.2	159	79%	-0.3	-0.8%
Kentucky	284	58.7	58.1	226	79%	-0.6	-1.0%
Louisiana	256	47.3	46.7	208	81%	-0.6	-1.4%
Maine	71	25.4	25.1	46	64%	-0.2	-0.9%
Maryland	206	81.6	81.0	124	60%	-0.6	-0.8%
Massachusetts	192	69.4	68.9	123	64%	-0.5	-0.8%
Michigan	483	133.4	132.5	350	72%	-0.9	-0.7%
Minnesota	319	103.1	102.5	216	68%	-0.6	-0.6%
Mississippi	195	32.5	32.1	162	83%	-0.4	-1.2%
Missouri	406	91.9	90.9	315	77%	-1	-1.0%
Montana	122	35.7	35.6	86	71%	-0.1	-0.4%
Nebraska	144	36.1	35.9	108	75%	-0.2	-0.6%
Nevada	123	32.9	32.7	90	73%	-0.2	-0.7%
New Hampshire	60	21.6	21.4	39	64%	-0.2	-0.8%
New Jersey	272	85.7	85.0	186	68%	-0.7	-0.8%
New Mexico	179	40.7	40.3	139	77%	-0.4	-0.9%
New York	472	196.4	194.3	276	58%	-2	-1.0%
North Carolina	444	86.9	86.3	357	80%	-0.6	-0.7%
North Dakota	80	23.3	23.1	57	71%	-0.2	-0.9%
Ohio	567	145.2	144.2	421	74%	-1	-0.7%
Oklahoma	295	62.7	62.1	233	79%	-0.6	-1.0%
Oregon	238	61.7	61.4	176	74%	-0.3	-0.5%
Pennsylvania	504	336.1	334.5	168	33%	-1.6	-0.5%
Rhode Island	38	11.6	11.4	26	69%	-0.1	-1.2%
South Carolina	285	56.4	55.8	229	80%	-0.6	-1.0%
South Dakota	78	22.1	21.9	56	72%	-0.1	-0.6%
Tennessee	385	78.6	77.8	307	80%	-0.9	-1.1%
Texas	1,045	244.6	241.2	800	77%	-3.4	-1.4%

Onroad Acetaldehyde	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Utah	219	65.2	64.6	153	70%	-0.7	-1.0%
Vermont	28	11.6	11.6	16	59%	0	-0.4%
Virginia	362	99.5	99.0	262	72%	-0.5	-0.5%
Washington	402	110.5	109.6	292	73%	-0.9	-0.9%
Virginia	110	22.6	22.3	87	79%	-0.2	-1.0%
Wisconsin	320	114.7	113.9	205	64%	-0.8	-0.7%
Wyoming	71	21.7	21.6	49	69%	-0.1	-0.6%

Table 4-6 Onroad Benzene Emissions (short tons)

Onroad Benzene	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Total (48 State)	29,554	6,870.3	6,758.3	22,683	77%	-112.0	-1.6%
Gasoline	28,584	6,808.3	6,696.3	21,776	76%	-112.0	-1.6%
Diesel	956	48.0	48.0	908	95%	0.0	0.0%
E85	13	5.8	5.8	7	55%	0.0	0.0%
CNG	1	8.4	8.4	-8	-900%	0.0	0.0%
Alabama	849	137.8	135.7	711	84%	-2.1	-1.5%
Arizona	686	145.4	139.7	540	79%	-5.7	-3.9%
Arkansas	369	66.9	65.8	302	82%	-1.1	-1.6%
California	2,349	769.6	760.6	1,579	67%	-8.9	-1.2%
Colorado	663	169.5	168.7	493	74%	-0.8	-0.4%
Connecticut	219	61.7	61.5	157	72%	-0.2	-0.3%
D.C.	35	7.7	7.5	27	78%	-0.1	-1.9%
Delaware	91	26.0	25.6	65	71%	-0.4	-1.4%
Florida	1,793	362.3	357.4	1,430	80%	-4.9	-1.4%
Georgia	1,196	226.9	219.5	969	81%	-7.4	-3.3%
Idaho	282	60.1	59.0	222	79%	-1.1	-1.9%
Illinois	993	260.7	256.0	733	74%	-4.7	-1.8%
Indiana	838	183.5	181.7	655	78%	-1.9	-1.0%
Iowa	458	98.8	97.9	359	78%	-0.8	-0.9%
Kansas	399	78.5	77.7	320	80%	-0.7	-0.9%
Kentucky	524	100.2	98.8	424	81%	-1.3	-1.3%
Louisiana	485	85.4	84.2	400	82%	-1.3	-1.5%
Maine	131	42.9	42.0	88	67%	-1.0	-2.2%
Maryland	370	108.1	106.1	262	71%	-2.1	-1.9%
Massachusetts	377	127.5	126.0	249	66%	-1.4	-1.1%
Michigan	1,067	270.7	266.2	796	75%	-4.5	-1.6%
Minnesota	735	214.3	212.0	521	71%	-2.3	-1.1%

Onroad Benzene	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Mississippi	406	63.5	62.6	343	84%	-0.8	-1.3%
Missouri	770	155.8	154.2	614	80%	-1.7	-1.1%
Montana	253	53.9	53.5	199	79%	-0.4	-0.7%
Nebraska	294	59.0	58.6	235	80%	-0.4	-0.7%
Nevada	265	59.2	58.6	205	78%	-0.6	-1.0%
New Hampshire	119	40.1	39.2	78	66%	-0.9	-2.2%
New Jersey	479	137.9	134.9	341	71%	-3.0	-2.2%
New Mexico	301	61.1	60.3	240	80%	-0.8	-1.3%
New York	832	272.1	261.7	560	67%	-10.4	-3.8%
North Carolina	1,064	197.8	195.9	866	81%	-2.0	-1.0%
North Dakota	120	32.9	32.6	87	73%	-0.3	-1.0%
Ohio	1,218	274.8	272.0	944	77%	-2.8	-1.0%
Oklahoma	568	111.4	109.8	456	80%	-1.5	-1.4%
Oregon	522	98.4	97.6	423	81%	-0.7	-0.7%
Pennsylvania	971	255.7	248.7	715	74%	-7.0	-2.7%
Rhode Island	67	19.9	19.4	47	70%	-0.5	-2.4%
South Carolina	614	107.5	106.5	507	82%	-1.0	-1.0%
South Dakota	151	37.1	36.8	114	75%	-0.2	-0.6%
Tennessee	814	149.7	147.5	664	82%	-2.2	-1.5%
Texas	1,803	342.1	332.4	1,461	81%	-9.7	-2.8%
Utah	373	108.3	107.0	265	71%	-1.3	-1.2%
Vermont	61	23.0	22.8	38	62%	-0.2	-0.7%
Virginia	771	159.1	157.9	612	79%	-1.2	-0.8%
Washington	895	194.0	190.2	701	78%	-3.9	-2.0%
Virginia	205	41.0	40.5	164	80%	-0.4	-1.1%
Wisconsin	590	185.7	182.5	404	69%	-3.1	-1.7%
Wyoming	120	25.1	24.9	95	79%	-0.2	-0.7%

Table 4-7 Onroad Formaldehyde Emissions (short tons)

Onroad Formaldehyde	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Total (48 State)	18,118	2,790.2	2,744.9	15,327	85%	-45.3	-1.6%
Gasoline	8,147	1,347.1	1,315.1	6,800	83%	-32.0	-2.4%
Diesel	9,816	905.1	891.9	8,911	91%	-13.2	-1.5%
E85	7	1.8	1.8	5	75%	0.0	0.0%
CNG	148	536.2	536.1	-389	-263%	0.0	0.0%
Alabama	473	44.0	43.1	429	91%	-0.8	-1.9%
Arizona	383	51.2	49.5	331	87%	-1.7	-3.3%

Onroad Formaldehyde	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Arkansas	264	25.0	24.5	239	91%	-0.5	-2.0%
California	1,436	281.0	276.9	1,156	80%	-4.0	-1.4%
Colorado	322	62.5	62.2	259	81%	-0.3	-0.5%
Connecticut	94	19.9	19.8	74	79%	-0.1	-0.6%
D.C.	24	10.9	10.9	13	55%	-0.1	-0.6%
Delaware	43	8.1	7.9	34	81%	-0.1	-1.8%
Florida	1,000	102.5	100.5	898	90%	-1.9	-1.9%
Georgia	727	95.8	93.5	631	87%	-2.3	-2.4%
Idaho	203	25.0	24.6	178	88%	-0.4	-1.7%
Illinois	608	135.1	133.1	473	78%	-2.0	-1.5%
Indiana	528	65.5	64.5	463	88%	-1.0	-1.5%
Iowa	256	32.9	32.5	223	87%	-0.4	-1.2%
Kansas	258	26.8	26.4	232	90%	-0.4	-1.4%
Kentucky	362	36.3	35.6	325	90%	-0.7	-1.8%
Louisiana	357	32.2	31.6	325	91%	-0.6	-1.9%
Maine	84	15.7	15.3	68	81%	-0.4	-2.3%
Maryland	250	59.1	58.2	191	76%	-0.9	-1.5%
Massachusetts	200	42.4	41.7	158	79%	-0.7	-1.7%
Michigan	498	79.9	78.5	418	84%	-1.5	-1.8%
Minnesota	337	57.1	56.2	280	83%	-0.9	-1.6%
Mississippi	252	21.0	20.7	231	92%	-0.4	-1.8%
Missouri	516	58.3	57.3	457	89%	-1.0	-1.7%
Montana	163	21.5	21.3	141	87%	-0.2	-0.8%
Nebraska	171	21.1	20.9	150	88%	-0.2	-1.0%
Nevada	158	22.2	21.9	135	86%	-0.3	-1.2%
New Hampshire	64	12.9	12.6	51	80%	-0.3	-2.4%
New Jersey	326	54.0	52.8	272	83%	-1.2	-2.3%
New Mexico	261	27.6	27.2	233	89%	-0.4	-1.4%
New York	631	147.8	144.3	483	77%	-3.5	-2.4%
North Carolina	511	55.2	54.5	456	89%	-0.7	-1.4%
North Dakota	119	13.9	13.7	105	88%	-0.2	-1.5%
Ohio	602	84.6	83.4	518	86%	-1.2	-1.5%
Oklahoma	388	40.2	39.5	348	90%	-0.7	-1.7%
Oregon	312	37.2	36.9	275	88%	-0.4	-0.9%
Pennsylvania	619	316.1	313.7	303	49%	-2.4	-0.8%
Rhode Island	44	6.8	6.6	37	84%	-0.2	-3.1%
South Carolina	362	41.3	40.7	321	89%	-0.6	-1.3%
South Dakota	103	13.3	13.2	90	87%	-0.1	-1.0%
Tennessee	467	50.1	49.2	417	89%	-1.0	-2.0%
Texas	1,419	152.8	148.6	1,266	89%	-4.2	-2.7%
Utah	322	42.9	42.3	279	87%	-0.7	-1.6%
Vermont	30	7.1	7.1	23	77%	-0.1	-0.9%
Virginia	408	66.5	65.9	342	84%	-0.6	-0.9%
Washington	512	67.3	65.8	445	87%	-1.5	-2.2%
Virginia	142	14.1	13.9	128	90%	-0.2	-1.6%

Onroad Formaldehyde	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Wisconsin	402	72.1	70.8	330	82%	-1.2	-1.7%
Wyoming	104	13.1	13.0	91	87%	-0.1	-0.9%

Table 4-8 Onroad Naphthalene Emissions (short tons)

Onroad Naphthalene	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
Total (48 State)	2,486	302.2	297.8	2,184	88%	-4.4	-1.5%
Gasoline	1,422	281.3	277.2	1,141	80%	-4.1	-1.5%
Diesel	1,063	20.8	20.5	1,043	98%	-0.3	-1.4%
E85	0	0.1	0.1	0	70%	0.0	0.0%
CNG	0	0.0	0.0	0	-671%	0.0	0.0%
Alabama	65	5.3	5.2	60	92%	-0.1	-1.4%
Arizona	53	5.9	5.7	47	89%	-0.2	-3.7%
Arkansas	35	3.0	2.9	32	92%	0.0	-1.5%
California	192	32.7	32.3	159	83%	-0.4	-1.3%
Colorado	47	7.2	7.1	40	85%	0.0	-0.4%
Connecticut	15	3.0	3.0	12	79%	0.0	-0.3%
D.C.	3	0.3	0.3	3	88%	0.0	-2.0%
Delaware	7	1.3	1.3	5	81%	0.0	-1.3%
Florida	138	13.2	13.0	125	90%	-0.2	-1.3%
Georgia	97	9.0	8.8	88	91%	-0.2	-2.7%
Idaho	27	2.6	2.6	24	90%	0.0	-1.5%
Illinois	85	12.9	12.7	72	85%	-0.2	-1.6%
Indiana	73	8.5	8.4	65	88%	-0.1	-1.0%
Iowa	37	4.6	4.6	32	87%	0.0	-0.7%
Kansas	36	3.5	3.5	32	90%	0.0	-0.9%
Kentucky	49	4.7	4.6	45	91%	-0.1	-1.3%
Louisiana	47	3.3	3.3	43	93%	0.0	-1.4%
Maine	12	2.1	2.0	10	82%	0.0	-1.9%
Maryland	34	5.3	5.2	29	84%	-0.1	-1.7%
Massachusetts	29	6.3	6.2	23	79%	-0.1	-1.1%
Michigan	76	12.6	12.4	63	83%	-0.2	-1.4%
Minnesota	51	9.2	9.1	42	82%	-0.1	-1.0%
Mississippi	34	2.5	2.5	32	93%	0.0	-1.2%
Missouri	70	7.2	7.2	63	90%	-0.1	-1.0%
Montana	22	2.4	2.4	20	89%	0.0	-0.6%
Nebraska	24	2.8	2.7	21	89%	0.0	-0.6%
Nevada	22	2.6	2.6	19	88%	0.0	-1.1%

Onroad Naphthalene	2016 base (short tons)	2045 ref (short tons)	2045 ctl (short tons)	absolute difference 2016 to 2045 ref (short tons)	% diff 2016 to 2045 ref	absolute difference 2045 ctl to 2045 ref (short tons)	% diff 2045 ctl to 2045 ref
New Hampshire	9	1.9	1.9	7	79%	0.0	-1.9%
New Jersey	44	6.9	6.7	38	85%	-0.1	-2.0%
New Mexico	34	2.8	2.7	31	92%	0.0	-1.2%
New York	82	12.6	12.2	69	85%	-0.4	-3.1%
North Carolina	74	7.9	7.8	66	89%	-0.1	-0.9%
North Dakota	15	1.5	1.5	14	90%	0.0	-0.9%
Ohio	90	12.7	12.6	77	86%	-0.1	-0.9%
Oklahoma	53	4.9	4.9	48	91%	-0.1	-1.2%
Oregon	43	4.1	4.1	39	90%	0.0	-0.7%
Pennsylvania	80	11.6	11.3	69	86%	-0.3	-2.3%
Rhode Island	6	1.0	1.0	5	84%	0.0	-2.2%
South Carolina	50	4.1	4.1	45	92%	0.0	-0.9%
South Dakota	14	1.6	1.6	12	89%	0.0	-0.6%
Tennessee	65	6.5	6.4	59	90%	-0.1	-1.4%
Texas	184	15.8	15.5	168	91%	-0.4	-2.4%
Utah	41	4.6	4.5	37	89%	0.0	-1.1%
Vermont	4	1.0	1.0	3	77%	0.0	-0.7%
Virginia	58	7.2	7.1	51	88%	-0.1	-0.7%
Washington	71	8.1	8.0	63	89%	-0.1	-1.8%
Virginia	19	1.8	1.8	17	91%	0.0	-1.0%
Wisconsin	55	8.4	8.3	47	85%	-0.1	-1.5%
Wyoming	13	1.2	1.2	12	91%	0.0	-0.6%

Table 4-9 Nonroad Emissions, Criteria Pollutants (short tons)

Pollutant	NOx		VOC		$PM_{2.5}$		CO	
Year	2016	2045	2016	2045	2016	2045	2016	2045
Total (48 State)	1,110,278	576,120	1,128,684	840,750	103,230	47,816	10,593,273	12,616,102
Gasoline	187,508	190,333	1,038,437	816,257	36,395	37,156	9,901,669	12,165,294
Diesel	851,442	286,643	80,199	12,696	64,634	5,748	421,392	63,868
Marine Diesel	28,190	31,141	1,459	2,283	592	765	5,532	8,195
CNG	6,487	9,012	2,494	2,598	225	477	46,575	75,744
LPG	36,651	58,991	6,095	6,916	1,383	3,671	218,105	303,001

Table 4-10 Nonroad Emissions, Toxic Pollutants (short tons)

Pollutant	Acetaldehyde		Benzene		Formaldehyde		Naphthalene	
Year	2016	2045	2016	2045	2016	2045	2016	2045
Total (48 State)	11,428	5,566	30,247	26,068	26,466	11,408	1,701	1,122
Gasoline	4,550	4,159	27,314	25,360	7,154	6,741	1,450	1,073

Diesel	6,638	1,057	2,820	537	17,624	2,612	245	38
Marine Diesel	131	236	56	122	365	660	6	11
CNG	73	76	14	14	1,181	1,231	0.1	0.1
LPG	37	38	44	34	142	164	0.4	0.4

5 Air Quality Modeling Methodology

This section describes the air quality modeling done to support the proposed rule. A national scale air quality modeling analysis was performed to estimate the impact of the proposed Option 1 on future ozone, fine particulate matter, nitrogen dioxide, CO, and select air toxics concentrations as well as nitrogen deposition levels and visibility impairment. The Community Multiscale Air Quality (CMAQ) model was used to model the air quality impacts. CMAQ simulates the physical and chemical processes involved in the formation, transport, and destruction of ozone, particulate matter, and air toxics. In addition to the CMAQ model, the modeling platform includes the emissions, meteorology, and initial and boundary condition data which are inputs to the model.

Air quality modeling decisions are made early in the analytical process to allow for sufficient time required to conduct emissions and air quality modeling. For this reason, the inventories used in the air quality modeling and benefits modeling, which are presented in Section 5.4 of the draft RIA (DRIA), are slightly different than the national-scale inventories presented in Section 5.3 of the DRIA. Although these inventories are consistent in many ways, there are some differences. Chapter 5.4 of the draft RIA has more detail on the differences between the air quality control scenario and national-scale inventories.

Air quality modeling was performed for three cases: a 2016 base year, a 2045 reference case projection without the proposed rule and a 2045 control case with the proposed Option 1. The year 2016 was selected for the base year because this is the most recent year for which EPA has a complete modeling platform at the time of emissions and air quality modeling.

5.1 Air Quality Model – CMAQ

CMAQ is a non-proprietary computer model that simulates the formation and fate of photochemical oxidants, primary and secondary PM concentrations, acid deposition, and air toxics, over regional and urban spatial scales for given inputs of meteorological conditions and emissions. CMAQ includes numerous science modules that simulate the emission, production, decay, deposition and transport of organic and inorganic gas-phase and particle pollutants in the atmosphere. The CMAQ model is a well-known and well-respected tool and has been used in numerous national and international applications.[23] The air quality modeling completed for the rulemaking proposal used the 2016v1 platform with the most recent multi-pollutant CMAQ code available at the time of air quality modeling (CMAQ version 5.3.1).[24] The 2016 CMAQ runs utilized the CB6r3 chemical mechanism (Carbon Bond with linearized halogen chemistry) for gas-phase chemistry, and AERO7 (aerosol model with non-volatile primary organic aerosol) for

[23] More information available at: https://www.epa.gov/cmaq.
[24] Model code for CMAQ v5.3.1 is available from the Community Modeling and Analysis System (CMAS) at: http://www.cmascenter.org.

aerosols. The CMAQ model is regularly peer-reviewed, CMAQ versions 5.2 and 5.3 beta were most recently peer-reviewed in 2019 for the U.S. EPA.[25]

5.2 CMAQ Domain and Configuration

The CMAQ modeling analyses used a domain covering the continental United States, as shown in Figure 5-1. This single domain covers the entire continental U.S. (CONUS) and large portions of Canada and Mexico using 12 km × 12 km horizontal grid spacing. The 2016 simulation used a Lambert Conformal map projection centered at (-97, 40) with true latitudes at 33 and 45 degrees north. The model extends vertically from the surface to 50 millibars (approximately 17,600 meters) using a sigma-pressure coordinate system with 35 vertical layers. Table 5-1 provides some basic geographic information regarding the CMAQ domains and Table 5-2 provides the vertical layer structure for the CMAQ domain.

Table 5-1 Geographic elements of domains used in air quality modeling

	CMAQ Modeling Configuration
Grid Resolution	12 km National Grid
Map Projection	Lambert Conformal Projection
Coordinate Center	97 deg W, 40 deg N
True Latitudes	33 deg N and 45 deg N
Dimensions	396 × 246 × 35
Vertical extent	35 Layers: Surface to 50 millibar level (see Table 5-2)

Table 5-2 Vertical layer structure for CMAQ domain

Vertical Layers	**Sigma P**	**Pressure (mb)**	**Approximate Height (m)**
35	0.0000	50.00	17,556
34	0.0500	97.50	14,780
33	0.1000	145.00	12,822
32	0.1500	192.50	11,282
31	0.2000	240.00	10,002
30	0.2500	287.50	8,901
29	0.3000	335.00	7,932
28	0.3500	382.50	7,064
27	0.4000	430.00	6,275
26	0.4500	477.50	5,553
25	0.5000	525.00	4,885

[25] The Sixth External Peer Review of the Community Multiscale Air Quality (CMAQ) Modeling System. Available online at: https://www.epa.gov/sites/production/files/2019-08/documents/sixth_cmaq_peer_review_comment_report_6.19.19.pdf.

Vertical Layers	Sigma P	Pressure (mb)	Approximate Height (m)
24	0.5500	572.50	4,264
23	0.6000	620.00	3,683
22	0.6500	667.50	3,136
21	0.7000	715.00	2,619
20	0.7400	753.00	2,226
19	0.7700	781.50	1,941
18	0.8000	810.00	1,665
17	0.8200	829.00	1,485
16	0.8400	848.00	1,308
15	0.8600	867.00	1,134
14	0.8800	886.00	964
13	0.9000	905.00	797
12	0.9100	914.50	714
11	0.9200	924.00	632
10	0.9300	933.50	551
9	0.9400	943.00	470
8	0.9500	952.50	390
7	0.9600	962.00	311
6	0.9700	971.50	232
5	0.9800	981.00	154
4	0.9850	985.75	115
3	0.9900	990.50	77
2	0.9950	995.25	38
1	0.9975	997.63	19
0	1.0000	1000.00	0

Figure 5-1 Map of the CMAQ 12 km modeling domain (noted by the purple box)

5.3 CMAQ Inputs

The key inputs to the CMAQ model include emissions from anthropogenic and biogenic sources, meteorological data, and initial and boundary conditions.

The emissions inputs are summarized in the earlier sections of this document.

The CMAQ meteorological input files were derived from simulations of the Weather Research and Forecasting Model (WRF) version 3.8 for the entire 2016 year.[26,27] The WRF Model is a state-of-the-science mesoscale numerical weather prediction system developed for both operational forecasting and atmospheric research applications.[28] The meteorological outputs

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[26] Skamarock, W.C., et al. (2008) A Description of the Advanced Research WRF Version 3. https://opensky.ucar.edu/islandora/object/technotes:500.

[27] USEPA (2019). Meteorological Model Performance for Annual 2016 Simulation WRF v3.8 https://www3.epa.gov/ttn/scram/reports/Met_Model_Performance-2016_WRF.pdf. EPA-454/R-19-010.

[28] http://wrf-model.org.

from WRF were processed to create 12 km model-ready inputs for CMAQ using the Meteorology-Chemistry Interface Processor (MCIP) version 4.3. These inputs included hourly varying horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer.[29]

The boundary and initial species concentrations were provided by a northern hemispheric CMAQ modeling platform for the year 2016.[30,31] The hemispheric-scale platform uses a polar stereographic projection at 108 km resolution to completely and continuously cover the northern hemisphere for 2016. Meteorology is provided by WRF v3.8. Details on the emissions used for hemispheric CMAQ can be found in the 2016 hemispheric emissions modeling platform TSD.[32] The atmospheric processing (transformation and fate) was simulated by CMAQ (v5.2.1) using the CB6r3 and the aerosol model with non-volatile primary organic carbon (AE6nvPOA). The CMAQ model also included the on-line windblown dust emission sources (excluding agricultural land), which are not always included in the regional platform but are important for large-scale transport of dust.

5.4 CMAQ Model Performance Evaluation

An operational model performance evaluation for ozone, $PM_{2.5}$ and its related speciated components, specific air toxics (i.e., formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein), as well as nitrate and sulfate deposition were conducted using 2016 State/local monitoring sites data in order to estimate the ability of the CMAQ modeling system to replicate the base year concentrations for the 12 km Continental United States domain (Section 5.2, Figure 5-1). Included in this evaluation are statistical measures of model versus observed pairs that were paired in space and time on a daily or weekly basis, depending on the sampling frequency of each network (measured data). For certain time periods with missing ozone, $PM_{2.5}$, air toxic observations and nitrate and sulfate deposition we excluded the CMAQ predictions from those time periods in our calculations. It should be noted when pairing model and observed data that each CMAQ concentration represents a grid-cell volume-averaged value, while the ambient network measurements are made at specific locations.

Model performance statistics were calculated for several spatial scales and temporal periods (statistics are defined in Section 5.4.2). Statistics were calculated for individual monitoring sites

[29] Byun, D.W., Ching, J. K.S. (1999). Science algorithms of EPA Models-3 Community Multiscale Air Quality (CMAQ) modeling system, EPA/600/R-99/030, Office of Research and Development. Please also see: https://www.cmascenter.org/.

[30] Henderson, B., et al. (2018) Hemispheric-CMAQ Application and Evaluation for 2016, Presented at 2019 CMAS Conference, available https://cmascenter.org/conference//2018/slides/0850_henderson_hemispheric-cmaq_application_2018.pptx.

[31] Mathur, R., et al. (2017) Extending the Community Multiscale Air Quality (CMAQ) modeling system to hemispheric scales: overview of process considerations and initial applications, Atmos. Chem. Phys., 17, 12449-12474, https://doi.org/10.5194/acp-17-12449-2017.

[32] USEPA (2019). Technical Support Document: Preparation of Emissions Inventories for the Version 7.1 2016 Hemispheric Emissions Modeling Platform. Office of Air Quality Planning and Standards.

and for each of the nine National Oceanic and Atmospheric Administration (NOAA) climate regions of the 12-km U.S. modeling domain (Figure 5-2).[33] The regions include the Northeast, Ohio Valley, Upper Midwest, Southeast, South, Southwest, Northern Rockies, Northwest and West[34,35] as were originally identified in Karl and Koss (1984).[36] The statistics for each site and climate region were calculated by season ("winter" is defined as average of December, January, and February; "spring" is defined as average of March, April, and May; "summer" is defined as average of June, July, and August; and "fall" is defined as average of September, October, and December). For 8-hour daily maximum ozone, we also calculated performance statistics by region for the May through September ozone season.[37] In addition to the performance statistics, we prepared several graphical presentations of model performance. These graphical presentations include regional maps which show the mean bias, mean error, normalized mean bias and normalized mean error calculated for each season at individual monitoring sites.

[33] NOAA, National Centers for Environmental Information scientists have identified nine climatically consistent regions within the contiguous U.S., http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php.
[34] The nine climate regions are defined by States where: Northeast includes CT, DE, ME, MA, MD, NH, NJ, NY, PA, RI, and VT; Ohio Valley includes IL, IN, KY, MO, OH, TN, and WV; Upper Midwest includes IA, MI, MN, and WI; Southeast includes AL, FL, GA, NC, SC, and VA; South includes AR, KS, LA, MS, OK, and TX; Southwest includes AZ, CO, NM, and UT; Northern Rockies includes MT, NE, ND, SD, WY; Northwest includes ID, OR, and WA; and West includes CA and NV.
[35] Note most monitoring sites in the West region are located in California (see Figure 5-2), therefore statistics for the West will be mostly representative of California ozone air quality.
[36] Karl, T. R. and Koss, W. J., 1984: "Regional and National Monthly, Seasonal, and Annual Temperature Weighted by Area, 1895-1983." Historical Climatology Series 4-3, National Climatic Data Center, Asheville, NC, 38 pp.
[37] In calculating the ozone season statistics, we limited the data to those observed and predicted pairs with observations that exceeded 60 ppb in order to focus on concentrations at the upper portion of the distribution of values.

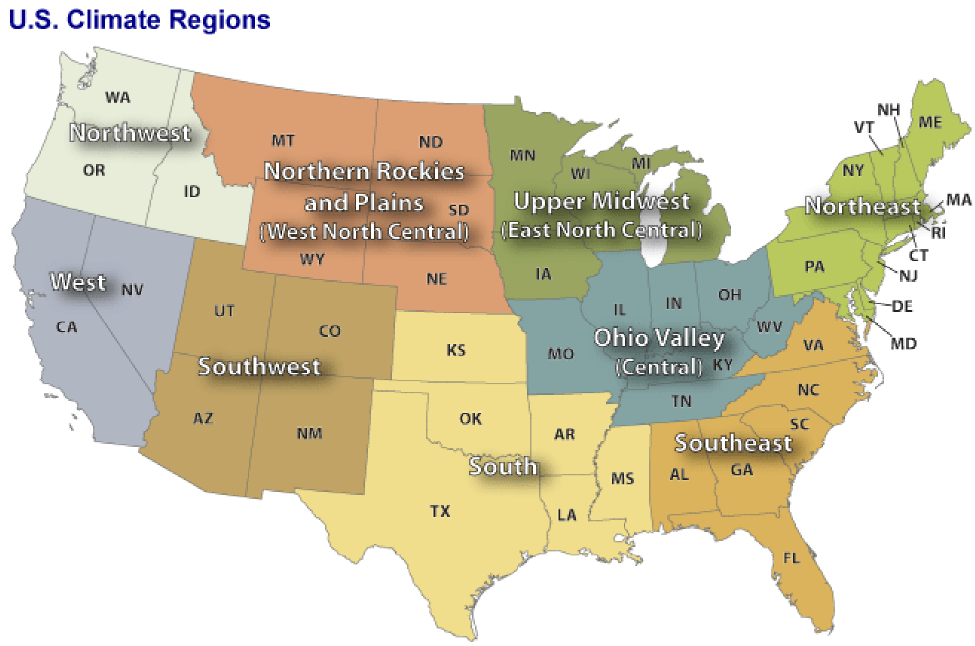

Figure 5-2 NOAA Nine Climate Regions (source: http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php#references**)**

5.4.1 Monitoring Networks

The model evaluation for ozone was based upon comparisons of model predicted 8-hour daily maximum concentrations to the corresponding ambient measurements for 2016 at monitoring sites in the EPA Air Quality System (AQS) and the Clean Air Status and Trends Network (CASTNet). The observed ozone data were measured and reported on an hourly basis. The $PM_{2.5}$ evaluation focuses on concentrations of $PM_{2.5}$ total mass and its components including sulfate (SO_4), nitrate (NO_3), total nitrate (TNO_3), ammonium (NH_4), elemental carbon (EC), and organic carbon (OC) as well as wet deposition for nitrate and sulfate. The $PM_{2.5}$ performance statistics were calculated for each season (e.g., "winter" is defined as December, January, and February). $PM_{2.5}$ ambient measurements for 2016 were obtained from the following networks: Chemical Speciation Network (CSN), Interagency Monitoring of PROtected Visual Environments (IMPROVE), Clean Air Status and Trends Network (CASTNet), and National Acid Deposition Program/National Trends (NADP/NTN). NADP/NTN collects and reports wet deposition measurements as weekly average data. The pollutant species included in the evaluation for each monitoring network are listed in Table 5-3. For $PM_{2.5}$ species that are measured by more than one network, we calculated separate sets of statistics for each network. The CSN and IMPROVE networks provide 24-hour average concentrations on a 1 in every 3-day, or 1 in every 6-day sampling cycle. The $PM_{2.5}$ species data at CASTNet sites are weekly integrated samples. In this analysis we use the term "urban sites" to refer to CSN sites; "suburban/rural sites" to refer to CASTNet sites; and "rural sites" to refer to IMPROVE sites.

Table 5-3 $PM_{2.5}$ monitoring networks and pollutants species included in the CMAQ performance evaluation

Ambient Monitoring Networks	Particulate Species							Wet Deposition Species	
	$PM_{2.5}$ Mass	SO_4	NO_3	TNO_3[a]	EC	OC	NH_4	SO_4	NO_3
IMPROVE	X	X	X		X	X			
CASTNet		X		X			X		
CSN	X	X	X		X	X	X		
NADP								X	X

[a] $TNO_3 = (NO_3 + HNO_3)$

The air toxics evaluation focuses on specific species relevant this proposed rulemaking, i.e., formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein. Similar to the $PM_{2.5}$ evaluation, the air toxics performance statistics were calculated for each season to estimate the ability of the CMAQ modeling system to replicate the base year concentrations for the 12 km continental U.S. domain. Toxic measurements for 2016 were obtained from the air toxics archive, https://www.epa.gov/amtic/amtic-air-toxics-data-ambient-monitoring-archive. While most of the data in the archive are from the AQS database including the National Air Toxics Trends Stations (NATTS), additional data (e.g., special studies) are included in the archive but not reported in the AQS.

5.4.2 Model Performance Statistics

The Atmospheric Model Evaluation Tool (AMET) was used to conduct the evaluation described in this document.[38] There are various statistical metrics available and used by the science community for model performance evaluation. For this evaluation of the 2016 CMAQ modeling platform, we have selected the mean bias, mean error, normalized mean bias, and normalized

[38] Appel, K.W., Gilliam, R.C., Davis, N., Zubrow, A., and Howard, S.C.: Overview of the Atmospheric Model Evaluation Tool (AMET) v1.1 for evaluating meteorological and air quality models, *Environ. Modell. Softw.*,26, 4, 434-443, 2011. (http://www.cmascenter.org/).

mean error to characterize model performance, statistics which are consistent with the recommendations in Simon et al. (2012)[39] and the draft photochemical modeling guidance.[40]

Mean bias (MB) is used as average of the difference (predicted – observed) divided by the total number of replicates (n). Mean bias is given in units of ppb and is defined as:

MB = $\frac{1}{n}\sum_{1}^{n}(P-O)$, where P = predicted and O = observed concentrations.

Mean error (ME) calculates the absolute value of the difference (predicted – observed) divided by the total number of replicates (n). Mean error is given in units of ppb and is defined as:

ME = $\frac{1}{n}\sum_{1}^{n}|P-O|$

Normalized mean bias (NMB) is used as a normalization to facilitate a range of concentration magnitudes. This statistic averages the difference (predicted – observed) over the sum of observed values. NMB is a useful model performance indicator because it avoids over inflating the observed range of values, especially at low concentrations. Normalized mean bias is given in percentage units and is defined as:

$$\mathrm{NMB} = \frac{\sum_{1}^{n}(P-O)}{\sum_{1}^{n}(O)} * 100$$

Normalized mean error (NME) is also similar to NMB, where the performance statistic is used as a normalization of the mean error. NME calculates the absolute value of the difference (predicted – observed) over the sum of observed values. Normalized mean error is given in percentage units and is defined as:

[39] Simon, H., Baker, K., Phillips, S., 2012: Compilation and interpretation of photochemical model performance statistics published between 2006 and 2012. Atmospheric Environment 61, 124-139.

[40] U.S. Environmental Protection Agency (US EPA), Draft Modeling Guidance for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze. December 2014, U.S. EPA, Research Triangle Park, NC, 27711.

$$\mathrm{NME} = \frac{\sum_{1}^{n} |P - O|}{\sum_{1}^{n} (O)} * 100$$

The “acceptability” of model performance was judged by comparing our CMAQ 2016 performance results in light of the range of performance found in recent regional ozone and $PM_{2.5}$ model applications.[41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51] These other modeling studies represent a wide range of modeling analyses that cover various models, model configurations, domains, years and/or episodes, chemical mechanisms, and aerosol modules. Overall, the ozone and $PM_{2.5}$ model performance results for the 2016 CMAQ simulations are within the range found in other recent peer-reviewed and regulatory applications. The model performance results, as described in this document, demonstrate that that our applications of CMAQ using this 2016 modeling platform provide a scientifically credible approach for assessing ozone and $PM_{2.5}$ concentrations

[41] National Research Council (NRC), 2002. Estimating the Public Health Benefits of Proposed Air Pollution Regulations, Washington, DC: National Academies Press.

[42] Appel, K.W., Roselle, S.J., Gilliam, R.C., and Pleim, J.E, 2010: Sensitivity of the Community Multiscale Air Quality (CMAQ) model v4.7 results for the eastern United States to MM5 and WRF meteorological drivers. Geoscientific Model Development, 3, 169-188.

[43] Foley, K.M., Roselle, S.J., Appel, K.W., Bhave, P.V., Pleim, J.E., Otte, T.L., Mathur, R., Sarwar, G., Young, J.O., Gilliam, R.C., Nolte, C.G., Kelly, J.T., Gilliland, A.B., and Bash, J.O., 2010: Incremental testing of the Community multiscale air quality (CMAQ) modeling system version 4.7. Geoscientific Model Development, 3, 205-226.

[44] Hogrefe, G., Civeroio, K.L., Hao, W., Ku, J-Y., Zalewsky, E.E., and Sistla, G., Rethinking the Assessment of Photochemical Modeling Systems in Air Quality Planning Applications. Air & Waste Management Assoc., 58:1086-1099, 2008.

[45] Phillips, S., K. Wang, C. Jang, N. Possiel, M. Strum, T. Fox, 2007. Evaluation of 2002 Multi-pollutant Platform: Air Toxics, Ozone, and Particulate Matter, 7th Annual CMAS Conference, Chapel Hill, NC, October 6-8, 2008. (http://www.cmascenter.org/conference/2008/agenda.cfm).

[46] Simon, H., Baker, K.R., and Phillips, S., 2012. Compilation and interpretation of photochemical model performance statistics published between 2006 and 2012. Atmospheric Environment 61, 124-139. http://dx.doi.org/10.1016/j.atmosenv.2012.07.012.

[47] Strum, M., Wesson, K., Phillips, S., Pollack, A., Shepard, S., Jimenez, M., M., Beidler, A., Wilson, M., Ensley, D., Cook, R., Michaels H., and Brzezinski, D. Link Based vs NEI Onroad Emissions Impact on Air Quality Model Predictions. 17th Annual International Emission Inventory Conference, Portland, Oregon, June 2-5, 2008. (http://www.epa.gov/ttn/chief/conference/ei17/session11/strum_pres.pdf).

[48] Tesche, T.W., Morris, R., Tonnesen, G., McNally, D., Boylan, J., Brewer, P., 2006. CMAQ/CAMx annual 2002 performance evaluation over the eastern United States. Atmospheric Environment 40, 4906-4919.

[49] U.S. Environmental Protection Agency; Technical Support Document for the Final Clean Air Interstate Rule: Air Quality Modeling; Office of Air Quality Planning and Standards; RTP, NC; March 2005 (CAIR Docket OAR-2005-0053-2149).

[50] U.S. Environmental Protection Agency, Proposal to Designate an Emissions Control Area for Nitrogen Oxides, Sulfur Oxides, and Particulate Matter: Technical Support Document. EPA-420-R-007, 329pp., 2009. (http://www.epa.gov/otaq/regs/nonroad/marine/ci/420r09007.pdf).

[51] U.S. Environmental Protection Agency, 2010, Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis. EPA-420-R-10-006. February 2010. Sections 3.4.2.1.2 and 3.4.3.3. Docket EPA-HQ-OAR-2009-0472-11332. (https://www.epa.gov/renewable-fuel-standard-program/renewable-fuel-standard-rfs2-final-rule-additional-resources).

for the purposes of this proposed rulemaking.

5.4.3 Evaluation for 8-hour Daily Maximum Ozone

The 8-hour ozone model performance bias and error statistics for each climate region, for each season defined above and for each monitor network (AQS and CASTNet) are provided in Table 5-4. As indicated by the statistics in Table 5-4, bias and error for 8-hour daily maximum ozone are relatively low in each climate region. Spatial plots of the mean bias and error as well as the normalized mean bias and error for individual monitors are shown in Figure 5-3 through Figure 5-6. The statistics shown in these figures were calculated over the ozone season using data pairs on days with observed 8-hour ozone of ≥ 60 ppb. Figure 5-3 shows MB for 8-hour ozone ≥ 60 ppb during the ozone season in the range of ±15 ppb at the majority of ozone AQS and CASTNet measurement sites. At both AQS and CASTNet sites, NMB is within the range of ±20 percent (Figure 5-5). Mean error for 8-hour maximum ozone ≥ 60 ppb, as seen from Figure 5-4, is 20 ppb or less at most of the sites across the modeling domain.

Table 5-4 Daily Maximum 8-hour Ozone Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2016 CMAQ Model Simulation

Climate Region	Monitor Network	Season	No. of Obs	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
Northeast	AQS	Winter	11,432	-1.8	4.7	-5.5	14.4
		Spring	15,682	-6.4	7.6	-14.4	17.1
		Summer	16,556	-0.4	6.4	-0.9	14.0
		Fall	13,676	0.4	4.7	1.1	13.6
	CASTNet	Winter	1,283	-2.5	4.7	-7.2	13.5
		Spring	1,336	-7.1	7.9	-15.7	17.7
		Summer	1,315	-1.6	5.9	-3.8	13.9
		Fall	1,306	0.4	4.6	1.11	13.5
Ohio Valley	AQS	Winter	4,177	0.4	4.6	1.4	15.2
		Spring	15,447	-4.0	6.3	-8.9	14.0
		Summer	20,418	1.2	6.4	2.7	14.2
		Fall	13,934	1.1	4.9	2.8	12.7
	CASTNet	Winter	1,574	-0.2	4.4	-0.7	13.5
		Spring	1,600	-5.1	6.9	-11.0	14.8
		Summer	1,551	-0.1	5.9	-0.2	13.5
		Fall	1,528	-1.1	5.0	-2.8	12.6
	AQS	Winter	1,719	-0.3	4.7	-1.0	15.0

Climate Region	Monitor Network	Season	No. of Obs	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
Upper Midwest		Spring	6,892	-6.1	7.7	-13.7	17.2
		Summer	9,742	-0.8	6.1	-1.8	14.5
		Fall	6,050	2.3	4.5	7.3	14.2
	CASTNet	Winter	435	-1.5	4.5	-4.5	13.5
		Spring	434	-7.8	8.5	-17.3	18.9
		Summer	412	-3.5	5.9	-8.6	14.2
		Fall	426	0.1	4.1	0.5	12.9
Southeast	AQS	Winter	7,153	-3.3	5.3	-9.0	14.7
		Spring	14,412	-5.4	7.0	-11.6	15.0
		Summer	15,573	0.4	5.3	0.9	13.4
		Fall	12,430	-0.8	4.6	-2.1	11.4
	CASTNet	Winter	887	-3.5	5.2	-9.5	13.8
		Spring	947	-7.2	8.1	-14.9	16.8
		Summer	926	-0.5	5.2	-1.3	13.2
		Fall	928	-2.3	5.2	-5.4	12.6
South	AQS	Winter	11,374	-2.1	5.3	-6.1	15.8
		Spring	13,041	-2.7	6.7	-6.2	15.2
		Summer	12,655	1.4	5.8	3.6	15.2
		Fall	12,280	0.0	4.8	-0.1	12.2
	CASTNet	Winter	523	-2.5	5.0	-6.9	13.8
		Spring	532	-4.5	6.8	-9.9	15.0
		Summer	508	-1.2	5.6	-3.2	14.5
		Fall	528	-0.6	4.2	-1.5	10.7
Southwest	AQS	Winter	9,636	-3.8	5.9	-9.9	15.1
		Spring	10,522	-7.6	8.4	-14.9	16.5
		Summer	10,500	-5.7	7.5	-10.5	14.0
		Fall	10,123	-0.9	4.4	-2.1	10.7
	CASTNet	Winter	757	-6.9	7.3	-15.4	16.3
		Spring	810	-9.2	9.5	-17.5	18.2

Climate Region	Monitor Network	Season	No. of Obs	MB (ppb)	ME (ppb)	NMB (%)	NME (%)
		Summer	812	-6.6	7.5	-12.3	14.0
		Fall	791	-3.0	4.2	-6.8	9.7
Northern Rockies	AQS	Winter	4,604	-2.1	5.1	-5.6	13.8
		Spring	4,917	-5.4	6.9	-12.5	15.9
		Summer	4,957	-2.7	5.4	-5.8	11.6
		Fall	4,774	0.7	4.5	2.2	13.5
	CASTNet	Winter	748	-3.1	5.9	-8.1	15.4
		Spring	783	-7.4	8.1	-16.0	17.6
		Summer	783	-4.9	6.0	-10.0	12.3
		Fall	687	-1.1	4.8	-2.9	13.0
Northwest	AQS	Winter	647	-3.0	6.1	-9.5	19.1
		Spring	1,288	-6.7	8.4	-16.5	20.7
		Summer	2,444	-1.5	6.3	-4.0	16.9
		Fall	1,176	1.1	5.3	3.6	17.0
	CASTNet	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-
West	AQS	Winter	14,521	-3.8	6.0	-10.9	17.3
		Spring	17,190	-7.8	8.4	-16.8	18.2
		Summer	17,969	-6.2	8.8	-11.6	16.4
		Fall	16,052	-4.0	6.4	-9.3	14.9
	CASTNet	Winter	506	-3.6	5.3	-9.1	13.4
		Spring	519	-8.2	8.5	-17.0	17.7
		Summer	526	-10.1	10.8	-16.7	17.9
		Fall	530	-5.2	6.3	-11.1	13.5

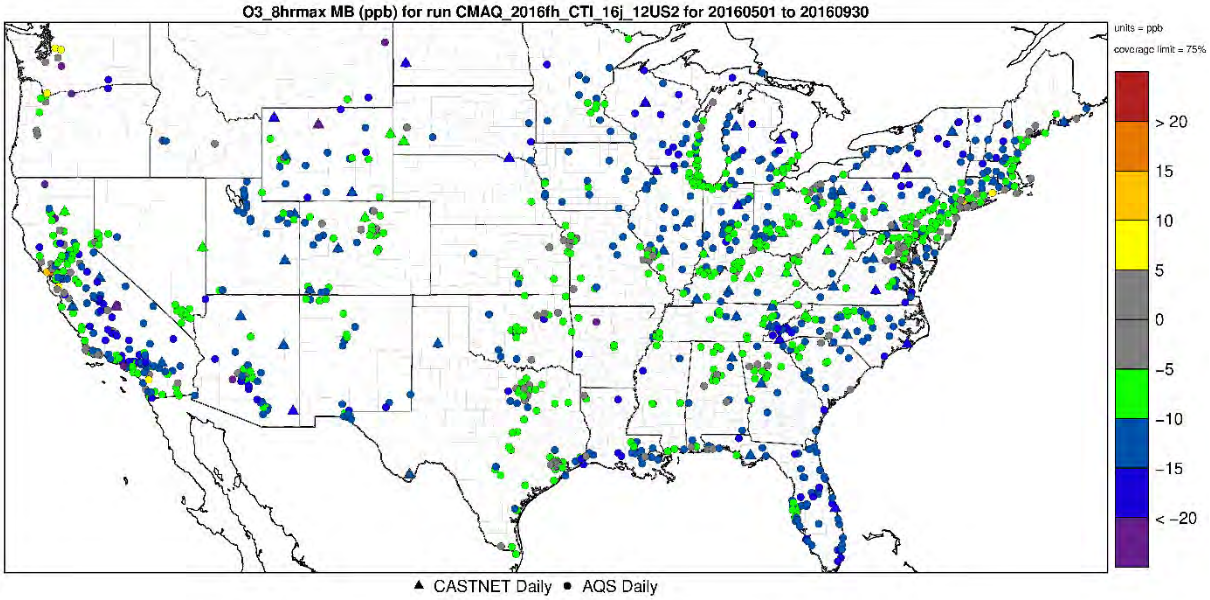

Figure 5-3 Mean Bias (ppb) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September 2016 at AQS and CASTNet monitoring sites in the modeling domain

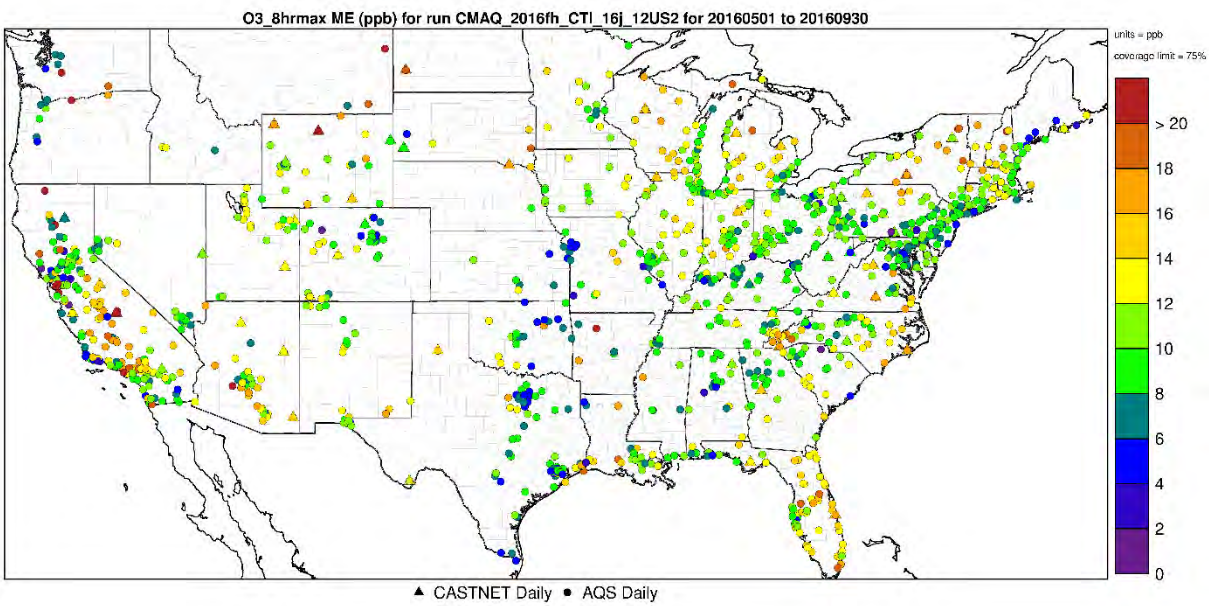

Figure 5-4 Mean Error (ppb) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September 2016 at AQS and CASTNet monitoring sites in the modeling domain

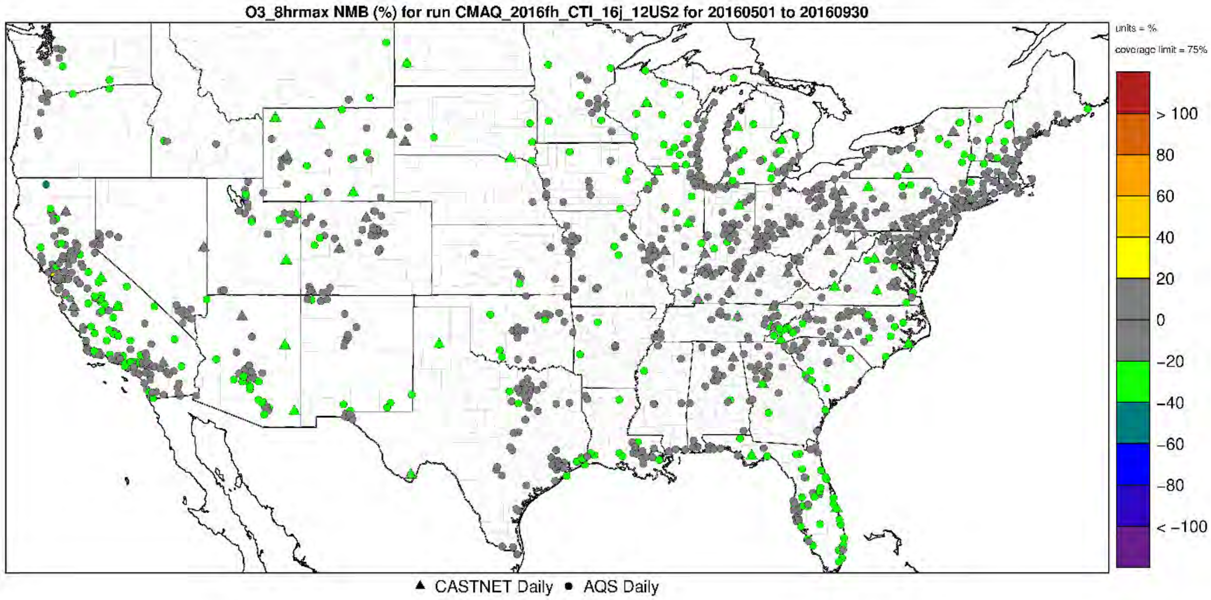

Figure 5-5 Normalized Mean Bias (%) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September AQS and CASTNet 2016 at monitoring sites in the modeling domain

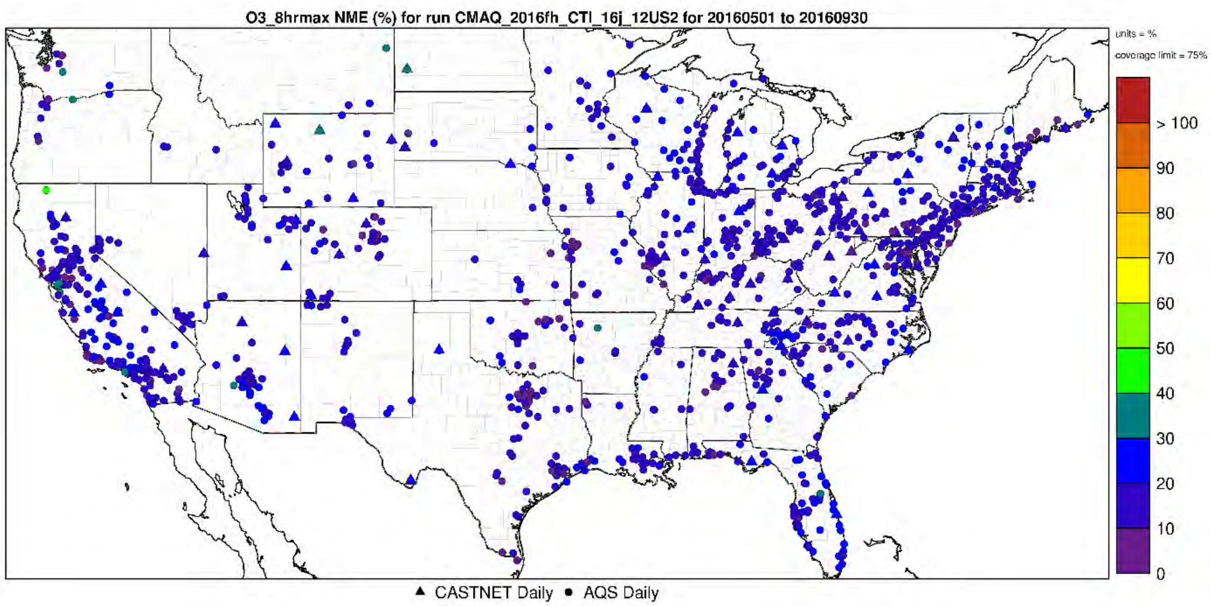

Figure 5-6 Normalized Mean Error (%) of 8-hour daily maximum ozone greater than 60 ppb over the period May-September AQS and CASTNet 2016 at monitoring sites in the modeling domain

5.4.4 Seasonal Evaluation of $PM_{2.5}$ Component Species

The evaluation of 2016 model predictions for $PM_{2.5}$ covers the performance for the individual $PM_{2.5}$ component species (i.e., sulfate, nitrate, organic carbon, elemental carbon, and ammonium). Performance results are provided for each $PM_{2.5}$ species. As indicated above, for each species we present tabular summaries of bias and error statistics by climate region for each season. These statistics are based on the set of observed-predicted pairs of data for the particular quarter at monitoring sites within the nine NOAA climate regions. Separate statistics are provided for each monitoring network, as applicable for the particular species measured. For sulfate and nitrate we also provide a more refined temporal and spatial analysis of model performance that includes spatial maps which show the mean bias and error and the normalized mean bias and error by site, aggregated by season.

5.4.4.1 Seasonal Evaluation for Sulfate

The model performance bias and error statistics for sulfate for each climate region and each season by monitor network are provided in Table 5-5. Spatial plots of the normalized mean bias and error by season for individual monitors are shown in Figure 5-7 through Figure 5-22.

Table 5-5 Sulfate Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2016 CMAQ Model Simulation

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	IMPROVE	Winter	431	0.0	0.2	-6.6	32.2
		Spring	477	0.0	0.2	0.3	30.1
		Summer	486	-0.1	0.3	-11.7	35.5
		Fall	456	0.0	0.2	-1.4	33.9
	CSN	Winter	721	0.0	0.4	1.6	41.8
		Spring	768	0.1	0.3	8.8	36.7
		Summer	755	-0.2	0.4	-19.2	30.4
		Fall	728	0.1	0.3	7.8	36.2
	CASTNet	Winter	221	-0.2	0.2	-23.6	25.1
		Spring	242	-0.2	0.2	-19.0	21.2
		Summer	239	-0.3	0.3	-27.5	28.2
		Fall	237	-0.2	0.2	-20.9	23.7
Ohio Valley	IMPROVE	Winter	220	-0.2	0.3	-18.1	30.9
		Spring	244	-0.2	0.3	-19.3	28.8
		Summer	239	-0.4	0.5	-27.3	36.6

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Fall	227	-0.3	0.4	-22.2	29.5
	CSN	Winter	518	-0.2	0.5	-16.2	35.7
		Spring	531	0.0	0.4	-0.6	33.3
		Summer	522	-0.2	0.5	-14.0	31.4
		Fall	511	-0.1	0.4	-4.5	31.2
	CASTNet	Winter	212	-0.4	0.4	-29.8	31.0
		Spring	228	-0.3	0.4	-24.9	26.2
		Summer	224	-0.5	0.5	-30.7	32.1
		Fall	226	-0.4	0.4	-27.7	28.0
Upper Midwest	IMPROVE	Winter	194	-0.1	0.2	-6.6	28.1
		Spring	208	0.0	0.2	-3.1	29.7
		Summer	210	-0.1	0.2	-20.0	33.1
		Fall	210	0.0	0.2	-4.8	36.0
	CSN	Winter	298	0.1	0.4	7.5	35.1
		Spring	323	0.2	0.4	19.2	38.6
		Summer	285	0.0	0.4	-2.7	34.3
		Fall	280	0.2	0.4	29.4	48.6
	CASTNet	Winter	71	-0.2	0.3	-23.9	27.3
		Spring	76	-0.1	0.1	-10.6	14.6
		Summer	76	-0.2	0.2	-19.8	23.4
		Fall	70	-0.1	0.2	-16.9	22.2
Southeast	IMPROVE	Winter	342	-0.1	0.3	-11.0	34.6
		Spring	379	-0.3	0.4	-23.1	30.8
		Summer	394	-0.5	0.5	-39.6	43.0
		Fall	366	-0.2	0.3	-20.4	28.1
	CSN	Winter	482	0.1	0.3	11.7	35.2
		Spring	522	0.0	0.3	-2.5	30.1
		Summer	492	-0.2	0.4	-22.5	32.9
		Fall	475	0.0	0.2	-0.3	25.0

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
	CASTNet	Winter	150	-0.3	0.4	-30.2	32.6
		Spring	164	-0.5	0.5	-34.3	34.9
		Summer	164	-0.6	0.6	-44.5	44.6
		Fall	154	-0.4	0.4	-32.4	33.0
South	IMPROVE	Winter	240	0.0	0.3	1.4	34.1
		Spring	273	-0.2	0.4	-16.5	38.1
		Summer	252	-0.7	0.7	-48.0	51.1
		Fall	264	-0.2	0.4	-20.1	34.6
	CSN	Winter	272	0.1	0.4	7.7	39.1
		Spring	287	-0.2	0.5	-12.4	38.5
		Summer	279	-0.5	0.7	-36.5	44.1
		Fall	269	-0.2	0.4	-13.4	29.5
	CASTNet	Winter	92	-0.3	0.3	-27.0	28.5
		Spring	102	-0.5	0.5	-33.0	33.9
		Summer	96	-0.9	0.9	-52.0	52.2
		Fall	102	-0.4	0.4	-31.4	32.2
Southwest	IMPROVE	Winter	910	0.1	0.2	59.1	84.0
		Spring	991	0.2	0.3	61.6	71.4
		Summer	985	-0.2	0.3	-38.0	48.5
		Fall	962	-0.1	0.2	-12.2	43.4
	CSN	Winter	240	0.0	0.4	9.2	74.4
		Spring	255	0.3	0.3	68.1	75.0
		Summer	249	-0.3	0.4	-34.5	48.5
		Fall	246	0.0	0.3	2.0	47.0
	CASTNet	Winter	101	0.1	0.1	37.6	59.7
		Spring	115	0.2	0.2	41.8	45.3
		Summer	114	-0.2	0.2	-35.7	40.6
		Fall	115	-0.1	0.2	-16.2	34.5
	IMPROVE	Winter	542	0.1	0.2	31.3	65.5

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northern Rockies		Spring	573	0.1	0.2	33.4	52.3
		Summer	603	0.0	0.2	4.4	41.6
		Fall	574	0.1	0.2	14.9	47.2
	CSN	Winter	137	0.1	0.3	16.9	51.1
		Spring	145	0.1	0.2	20.2	45.6
		Summer	135	0.0	0.2	-4.2	38.4
		Fall	136	0.1	0.2	10.6	41.8
	CASTNet	Winter	138	-0.1	0.2	-12.9	36.2
		Spring	152	0.0	0.1	5.2	26.8
		Summer	151	-0.1	0.1	-20.7	29.0
		Fall	142	0.0	0.1	-9.9	29.7
Northwest	IMPROVE	Winter	427	0.1	0.1	77.9	98.0
		Spring	505	0.2	0.2	60.3	69.8
		Summer	519	0.0	0.2	10.1	50.4
		Fall	499	0.1	0.2	33.4	69.9
	CSN	Winter	141	0.3	0.4	>100	>100
		Spring	146	0.3	0.4	85.8	89.9
		Summer	153	0.1	0.3	19.0	55.0
		Fall	146	0.3	0.4	80.8	>100
	CASTNet	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-
West	IMPROVE	Winter	565	0.2	0.2	80.2	>100
		Spring	608	0.1	0.3	25.3	57.3
		Summer	603	-0.2	0.3	-30.9	47.7
		Fall	576	0.0	0.2	-6.9	47.6
	CSN	Winter	330	0.1	0.3	29.3	68.8
		Spring	351	0.0	0.4	-1.8	48.2

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Summer	325	-0.7	0.8	-48.5	53.9
		Fall	317	-0.2	0.4	-19.2	45.3
	CASTNet	Winter	69	0.1	0.2	31.1	65.1
		Spring	73	-0.1	0.2	-11.1	37.7
		Summer	75	-0.5	0.5	-49.4	52.0
		Fall	77	-0.2	0.3	-30.1	42.6

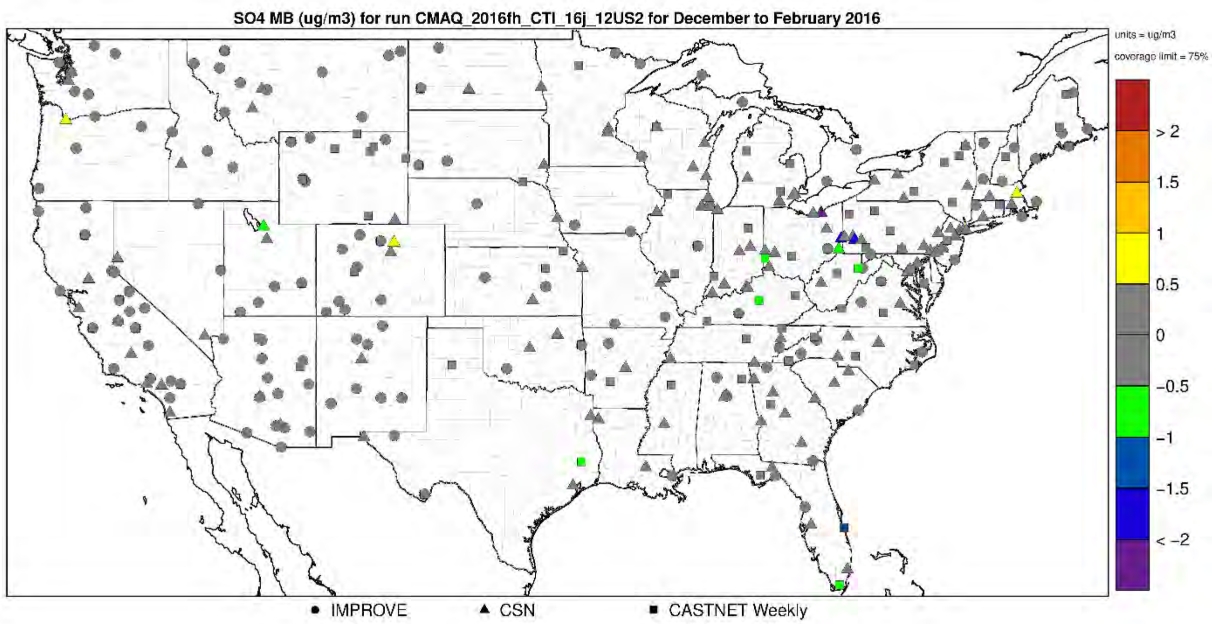

Figure 5-7 Mean Bias (ug/m3) of sulfate during winter 2016 at monitoring sites in the modeling domain

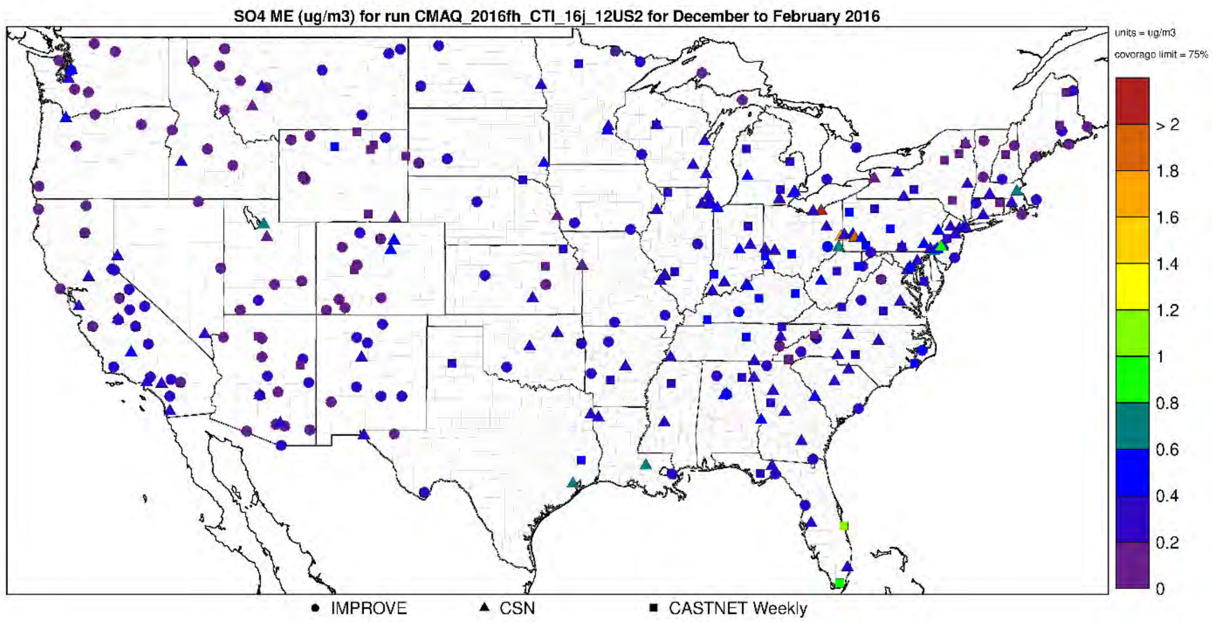

Figure 5-8 Mean Error (ug/m3) of sulfate during winter 2016 at monitoring sites in the modeling domain

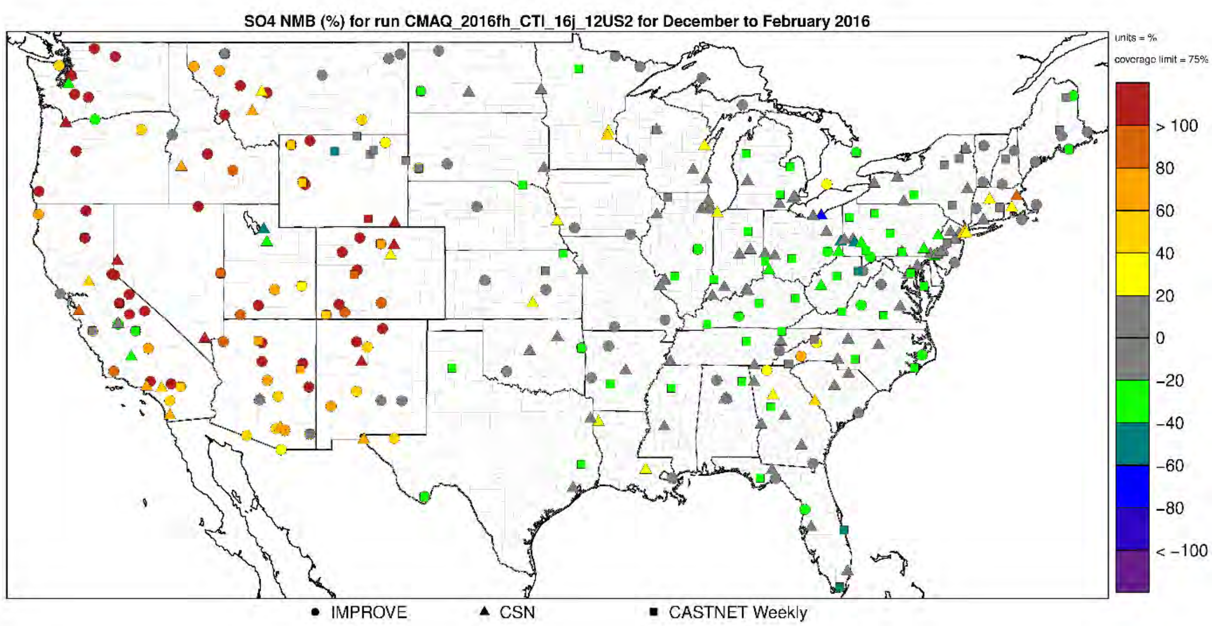

Figure 5-9 Normalized Mean Bias (%) of sulfate during winter 2016 at monitoring sites in the modeling domain

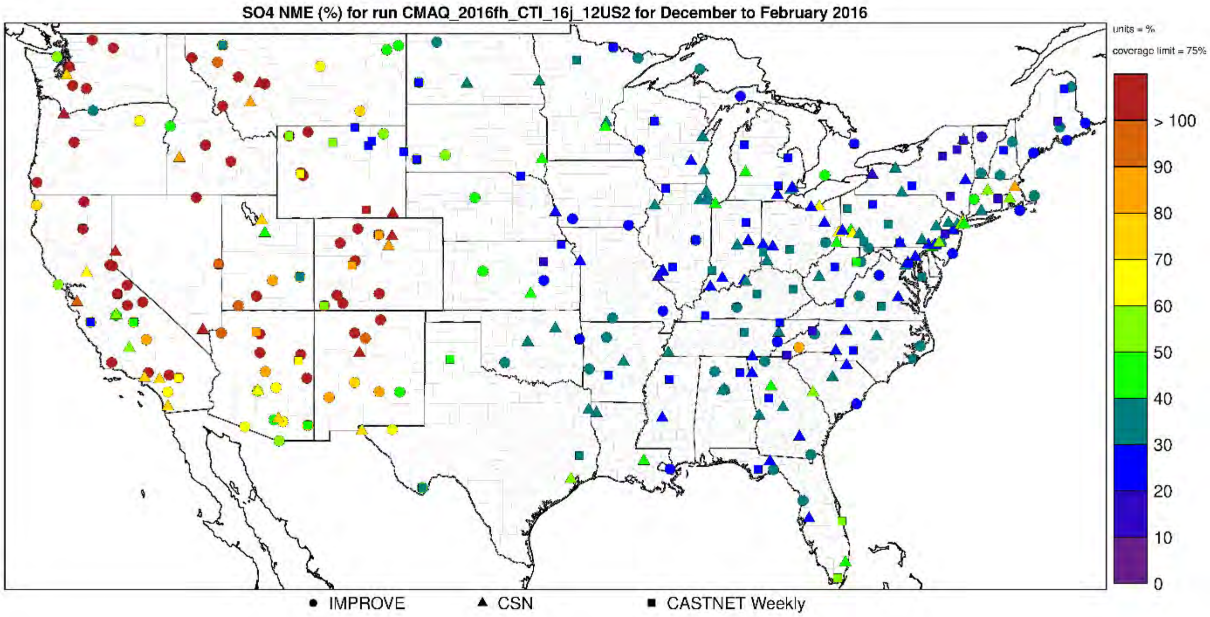

Figure 5-10 Normalized Mean Error (%) of sulfate during winter 2016 at monitoring sites in the modeling domain

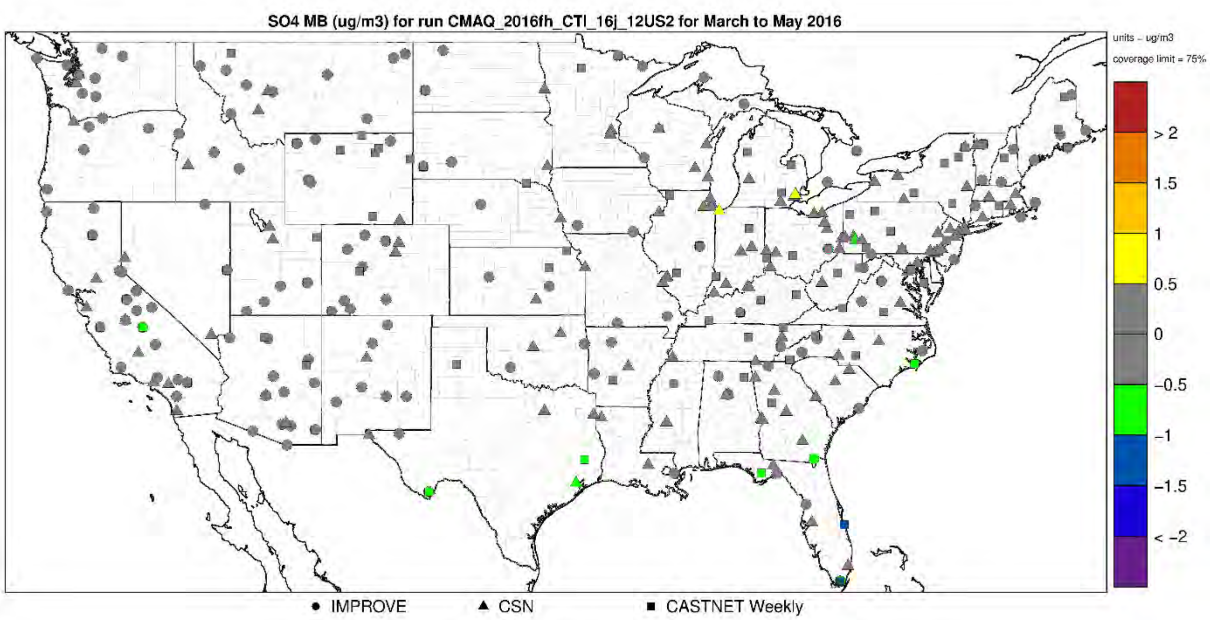

Figure 5-11 Mean Bias (ug/m^3) of sulfate during spring 2016 at monitoring sites in the modeling domain

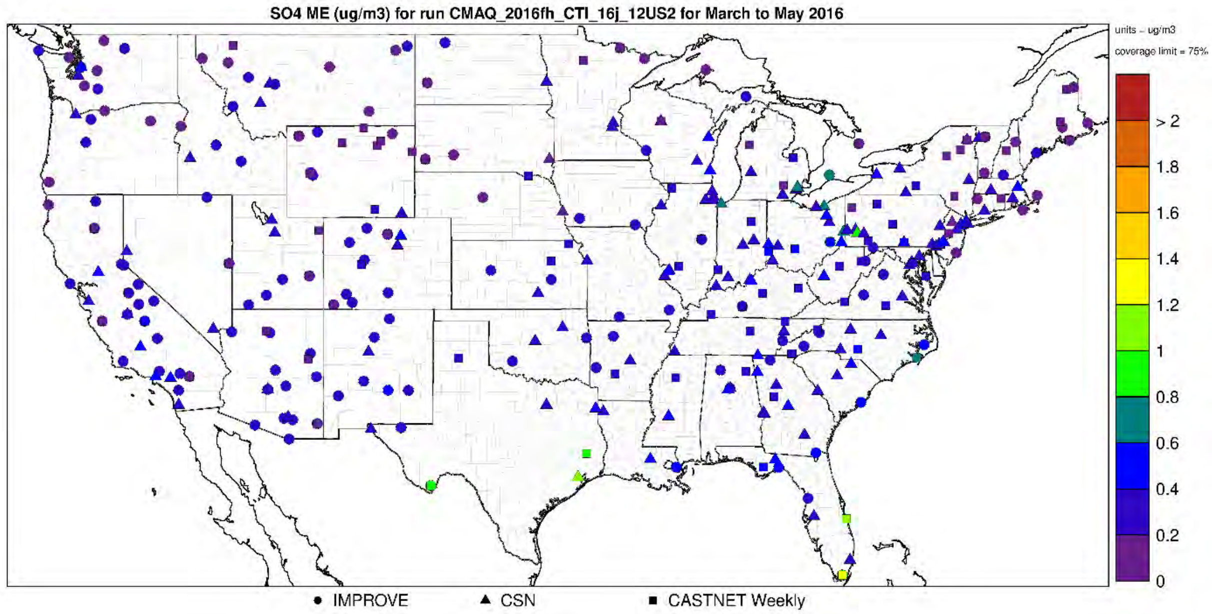

Figure 5-12 Mean Error (ug/m^3) of sulfate during spring 2016 at monitoring sites in the modeling domain

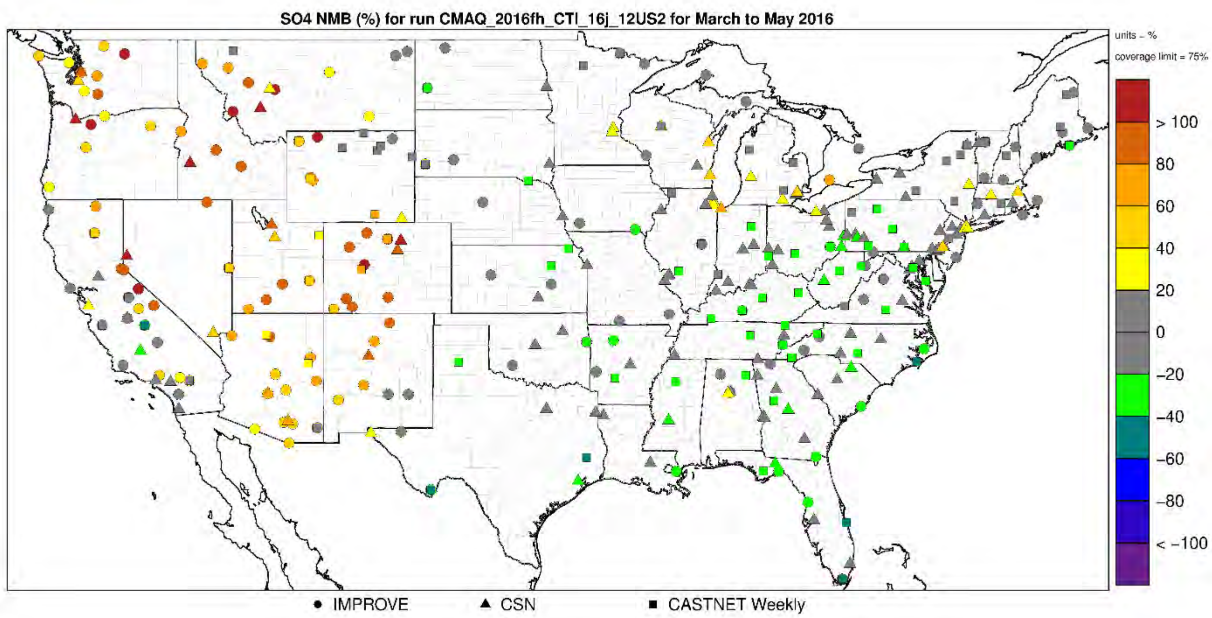

Figure 5-13 Normalized Mean Bias (%) of sulfate during spring 2016 at monitoring sites in the modeling domain

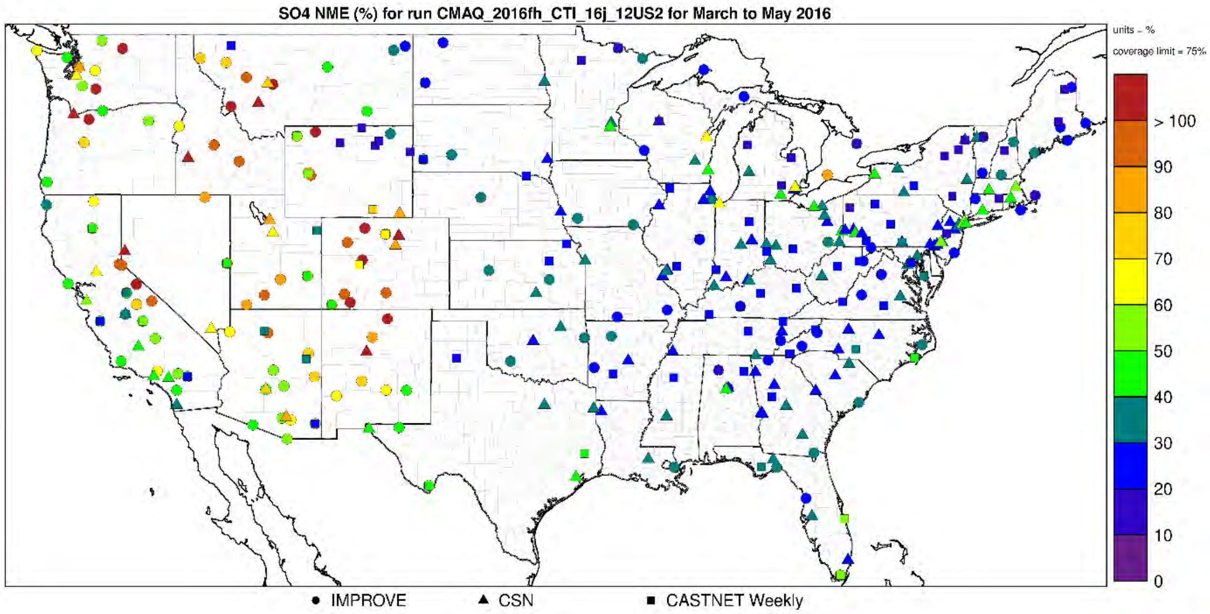

Figure 5-14 Normalized Mean Error (%) of sulfate during spring 2016 at monitoring sites in the modeling domain

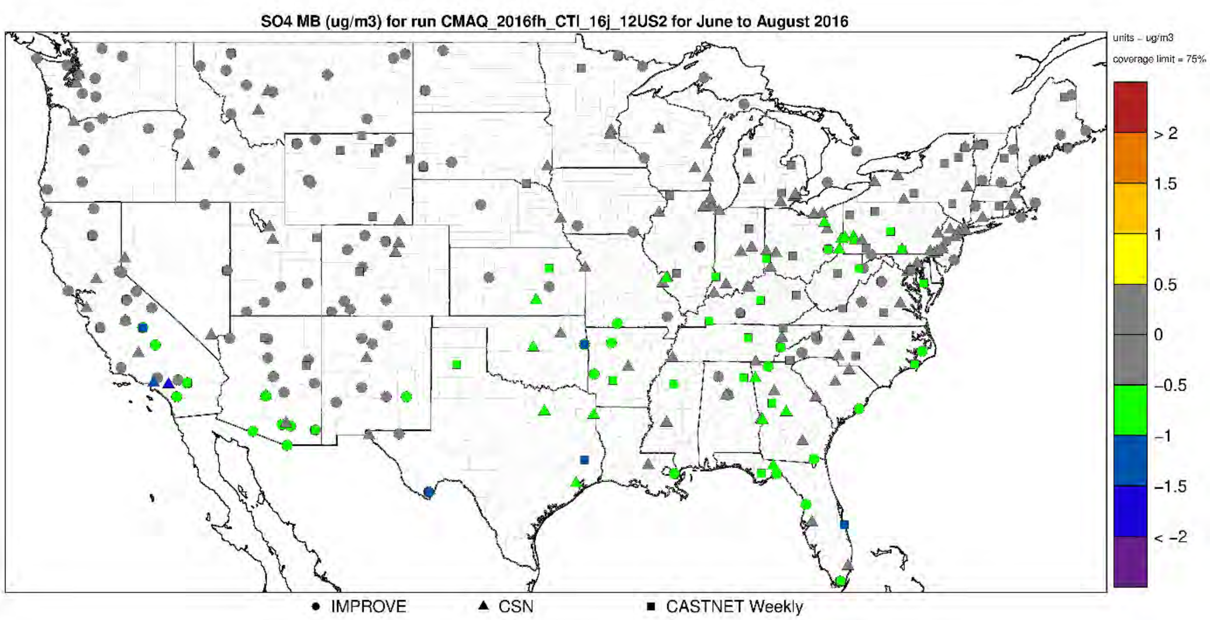

Figure 5-15 Mean Bias (ug/m3) of sulfate during summer 2016 at monitoring sites in the modeling domain

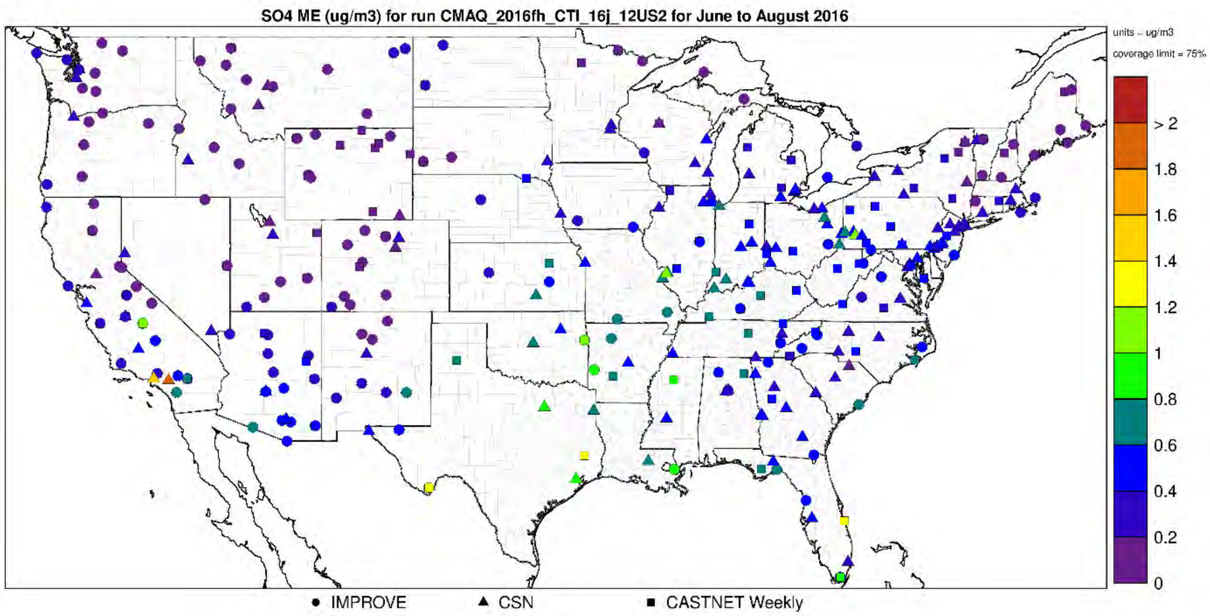

Figure 5-16 Mean Error (ug/m3) of sulfate during summer 2016 at monitoring sites in the modeling domain

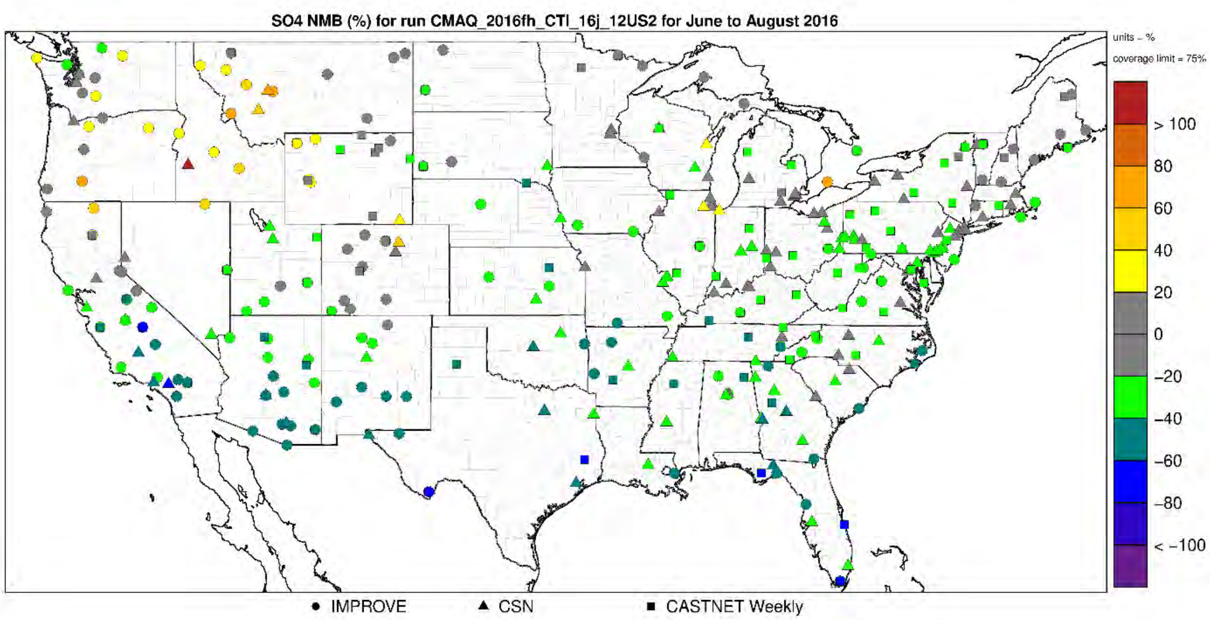

Figure 5-17 Normalized Mean Bias (%) of sulfate during summer 2016 at monitoring sites in the modeling domain

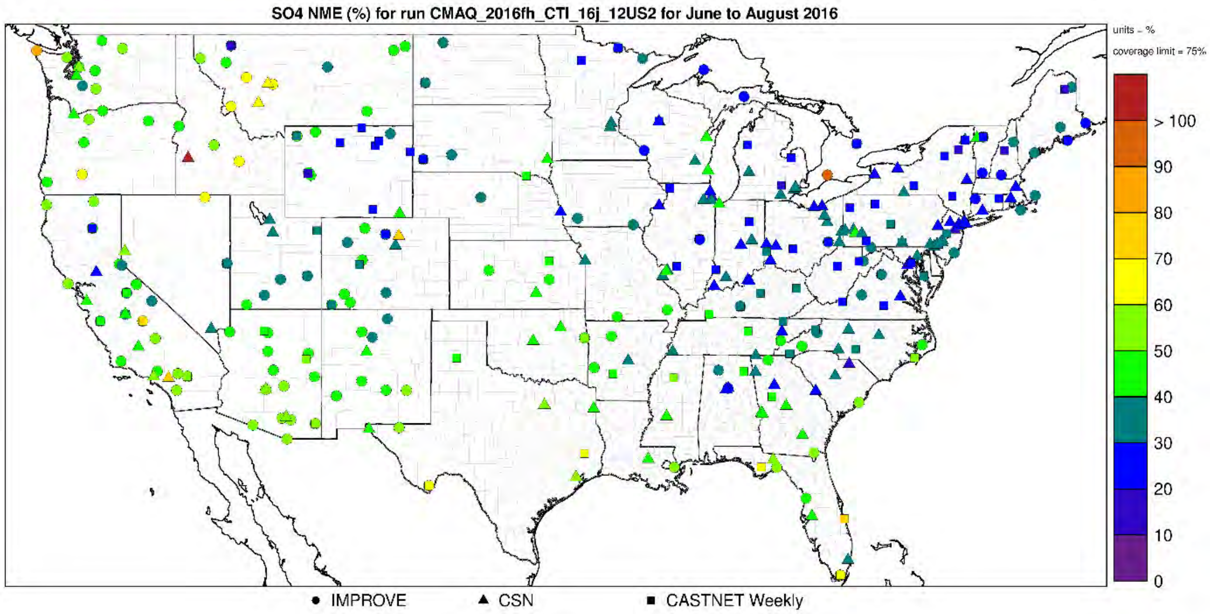

Figure 5-18 Normalized Mean Error (%) of sulfate during summer 2016 at monitoring sites in the modeling domain

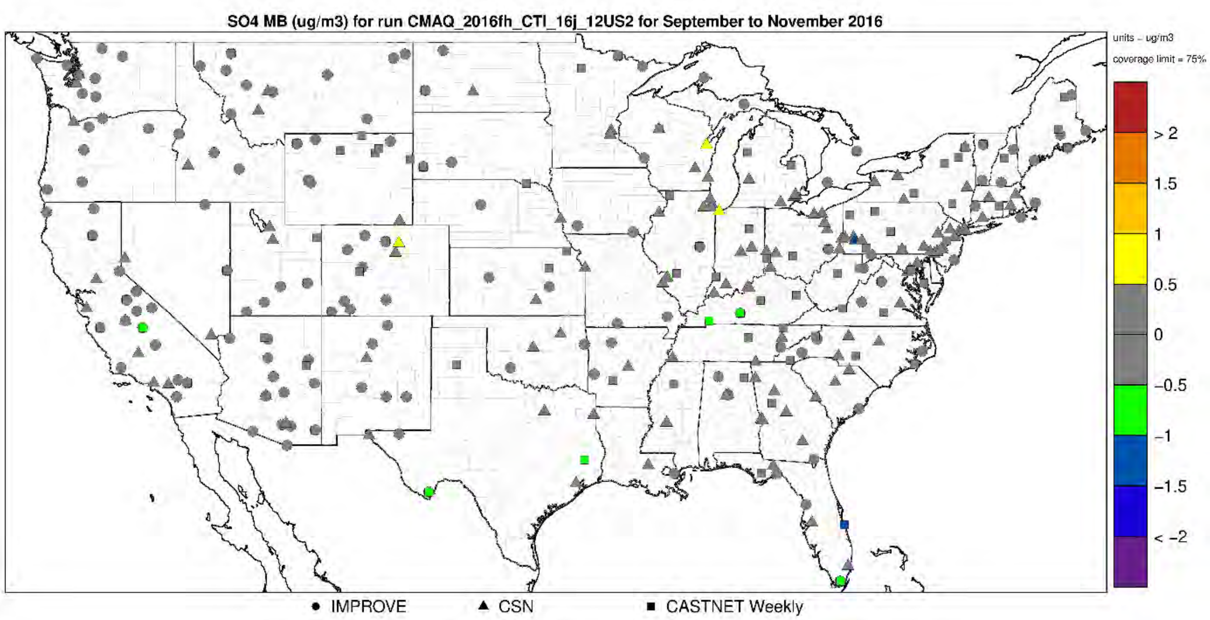

Figure 5-19 Mean Bias (ug/m^3) of sulfate during fall 2016 at monitoring sites in the modeling domain

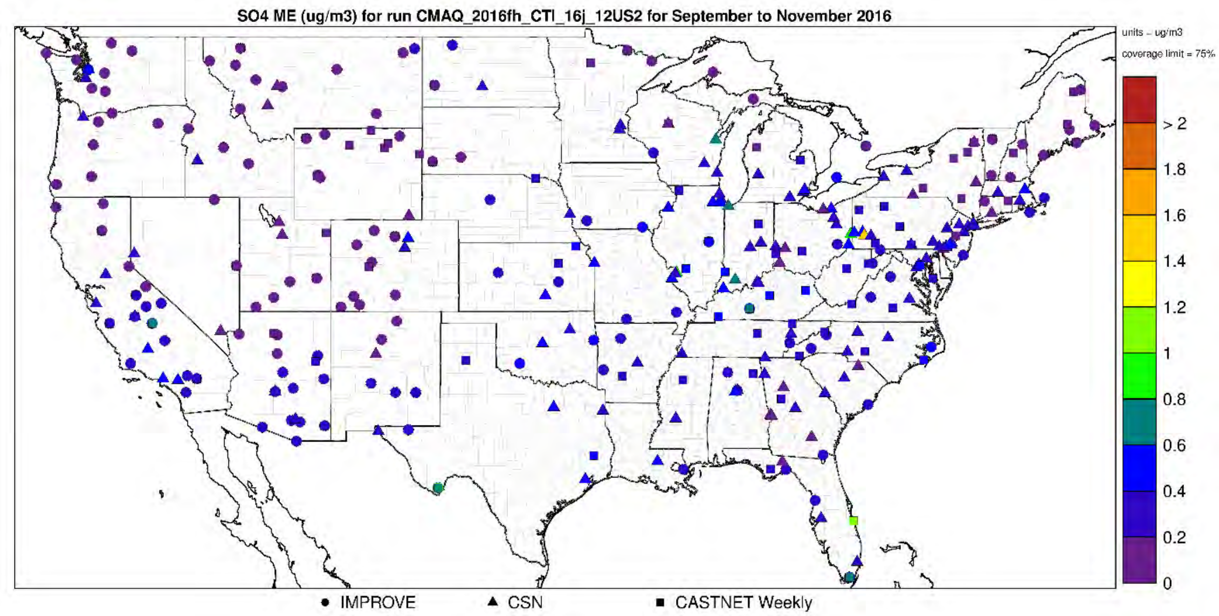

Figure 5-20 Mean Error (ug/m^3) of sulfate during fall 2016 at monitoring sites in the modeling domain

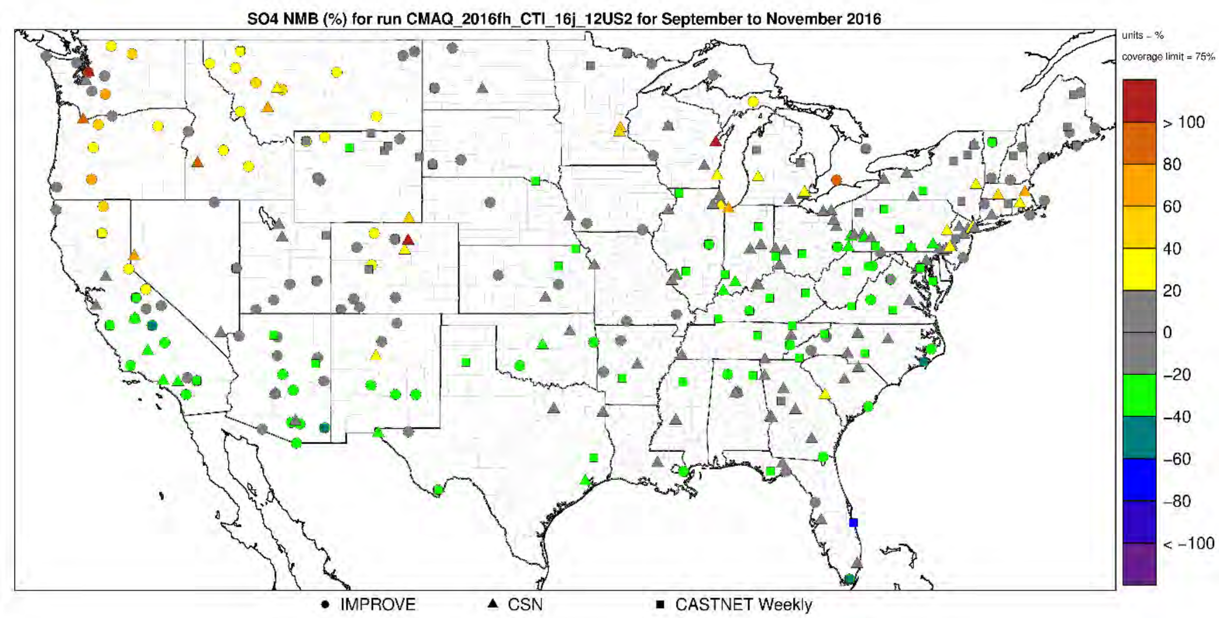

Figure 5-21 Normalized Mean Bias (%) of sulfate during fall 2016 at monitoring sites in the modeling domain

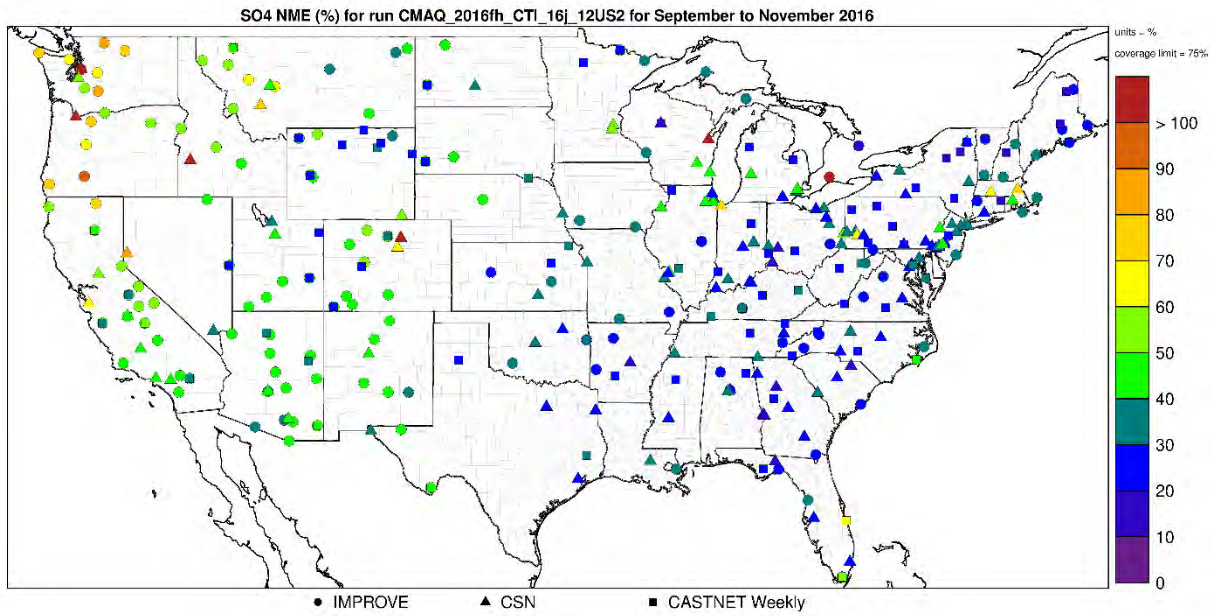

Figure 5-22 Normalized Mean Error (%) of sulfate during fall 2016 at monitoring sites in the modeling domain

5.4.4.2 Seasonal Evaluation for Nitrate

The model performance bias and error statistics for nitrate for each climate region and each season are provided in Table 5-6. This table includes statistics for particulate nitrate as measured at CSN and IMPROVE sites and total nitrate ($TNO_3=NO_3+HNO_3$) as measured at CASTNet sites. Spatial plots of the mean bias and error as well as normalized mean bias and error by season for individual monitors are shown in Figure 5-23 through Figure 5-54.

Table 5-6 Nitrate and Total Nitrate Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2016 CMAQ Model Simulation

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	IMPROVE (NO_3)	Winter	431	0.5	0.6	97.9	>100
		Spring	477	-0.1	0.3	-15.6	84.8
		Summer	486	0.0	0.2	-8.4	99.1
		Fall	456	0.0	0.2	-12.5	90.4
	CSN (NO_3)	Winter	720	0.7	1.0	39.5	59.7
		Spring	770	-0.2	0.5	-26.8	55.4
		Summer	751	-0.2	0.3	-69.5	79.8
		Fall	729	-0.2	0.4	-26.5	58.7

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
	CASTNet (TNO_3)	Winter	221	0.1	0.3	8.7	22.5
		Spring	242	-0.3	0.3	-22.8	30.3
		Summer	239	0.0	0.3	-4.4	28.0
		Fall	237	-0.1	0.3	-8.5	30.7
Ohio Valley	IMPROVE (NO_3)	Winter	220	-0.3	0.7	-26.0	52.8
		Spring	244	-0.4	0.4	-69.4	74.2
		Summer	239	-0.1	0.2	-73.1	80.8
		Fall	227	-0.4	0.4	-71.8	82.0
	CSN (NO_3)	Winter	515	-0.2	1.0	-6.6	41.6
		Spring	531	-0.3	0.6	-31.2	63.2
		Summer	521	-0.2	0.3	-51.0	80.1
		Fall	508	-0.3	0.5	-35.3	61.3
	CASTNet (TNO_3)	Winter	212	-0.5	0.6	-19.0	24.4
		Spring	228	-0.5	0.6	-31.6	34.0
		Summer	224	-0.1	0.4	-6.1	27.4
		Fall	226	-0.2	0.5	-13.7	33.3
Upper Midwest	IMPROVE (NO_3)	Winter	194	-0.4	0.7	-24.8	51.1
		Spring	208	-0.4	0.4	-64.7	70.3
		Summer	210	-0.1	0.1	-69.6	75.9
		Fall	210	-0.2	0.3	-57.5	76.1
	CSN (NO_3)	Winter	298	0.0	1.0	-1.6	37.9
		Spring	323	-0.2	0.7	-19.9	57.7
		Summer	284	-0.1	0.3	-36.5	91.9
		Fall	277	-0.2	0.5	-24.9	63.8
	CASTNet (TNO_3)	Winter	71	-0.6	0.7	-24.1	28.5
		Spring	76	-0.4	0.5	-30.6	36.3
		Summer	76	-0.1	0.2	-14.9	29.1
		Fall	70	-0.3	0.4	-28.6	33.5
Southeast	IMPROVE	Winter	342	0.0	0.3	-1.1	62.6

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
	(NO_3)	Spring	379	-0.2	0.3	-55.8	75.2
		Summer	394	-0.1	0.1	-30.9	76.9
		Fall	366	-0.1	0.2	-47.8	71.4
	CSN (NO_3)	Winter	483	0.3	0.5	52.0	83.3
		Spring	522	-0.1	0.2	-42.2	71.9
		Summer	491	-0.1	0.2	-28.8	92.5
		Fall	480	-0.1	0.2	-17.4	72.2
	CASTNet (TNO_3)	Winter	150	-0.2	0.4	-14.8	33.0
		Spring	164	-0.6	0.6	-46.8	47.8
		Summer	164	-0.3	0.4	-26.8	38.8
		Fall	154	-0.3	0.5	-23.4	39.6
South	IMPROVE (NO_3)	Winter	92	-0.5	0.6	-45.9	52.8
		Spring	102	-0.5	0.5	-79.8	80.3
		Summer	96	-0.5	0.5	-92.5	92.5
		Fall	102	-0.5	0.5	-85.5	85.5
	CSN (NO_3)	Winter	272	-0.1	0.5	-13.2	53.3
		Spring	285	-0.2	0.3	-52.2	72.4
		Summer	278	-0.1	0.2	-44.8	77.0
		Fall	270	-0.1	0.3	-41.7	72.8
	CASTNet (TNO_3)	Winter	92	-0.5	0.5	-27.5	32.2
		Spring	102	-0.5	0.5	-40.5	41.0
		Summer	96	-0.5	0.5	-39.1	41.8
		Fall	102	-0.3	0.4	-21.8	33.5
Southwest	IMPROVE (NO_3)	Winter	240	-0.3	0.5	-33.1	58.4
		Spring	273	-0.2	0.3	-62.1	78.8
		Summer	252	-0.2	0.2	-80.2	86.5
		Fall	264	-0.2	0.2	-74.5	80.2
	CSN (NO_3)	Winter	272	-0.1	0.5	-13.2	53.3
		Spring	285	-0.2	0.3	-52.2	72.4

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Summer	278	-0.1	0.2	-44.8	77.0
		Fall	270	-0.1	0.3	-41.7	72.8
	CASTNet (TNO_3)	Winter	101	-0.3	0.3	-41.5	51.3
		Spring	115	-0.2	0.2	-40.0	44.2
		Summer	114	-0.4	0.4	-47.4	49.1
		Fall	115	-0.1	0.2	-20.5	35.9
Northern Rockies	IMPROVE (NO_3)	Winter	542	-0.1	0.3	-30.2	64.3
		Spring	573	-0.1	0.1	-58.3	75.0
		Summer	603	-0.1	0.1	-89.1	94.2
		Fall	574	0.0	0.1	-28.0	84.2
	CSN (NO_3)	Winter	137	-0.1	0.7	-9.5	53.9
		Spring	145	-0.2	0.3	-41.2	57.9
		Summer	135	-0.1	0.1	-67.9	87.9
		Fall	135	-0.1	0.2	-24.3	70.4
	CASTNet (TNO_3)	Winter	138	-0.3	0.4	-38.8	44.0
		Spring	152	-0.2	0.2	-39.7	41.2
		Summer	151	-0.3	0.3	-39.2	39.4
		Fall	142	-0.1	0.2	-27.5	33.7
Northwest	IMPROVE (NO_3)	Winter	427	-0.1	0.3	-26.6	98.4
		Spring	505	0.0	0.2	28.8	>100
		Summer	519	0.1	0.2	77.5	>100
		Fall	499	0.0	0.2	9.5	>100
	CSN (NO_3)	Winter	142	-0.2	1.1	-17.0	86.3
		Spring	146	0.7	0.8	>100	>100
		Summer	153	1.2	1.2	>100	>100
		Fall	146	0.5	0.8	>100	>100
	CASTNet (TNO_3)	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Fall	-	-	-	-	-
West	IMPROVE (NO_3)	Winter	565	-0.3	0.3	-57.2	69.8
		Spring	608	-0.2	0.3	-60.5	71.0
		Summer	603	-0.2	0.3	-61.5	87.8
		Fall	576	-0.3	0.3	-70.3	79.8
	CSN (NO_3)	Winter	331	-2.3	2.4	-67.8	70.8
		Spring	351	-1.1	1.1	-69.2	72.8
		Summer	324	-0.8	0.9	-64.1	71.5
		Fall	319	-1.5	1.6	-74.6	79.2
	CASTNet (TNO_3)	Winter	69	-0.4	0.4	-51.5	55.6
		Spring	73	-0.5	0.5	-52.3	52.6
		Summer	75	-0.9	0.9	-51.7	52.1
		Fall	77	-0.6	0.6	-49.0	52.0

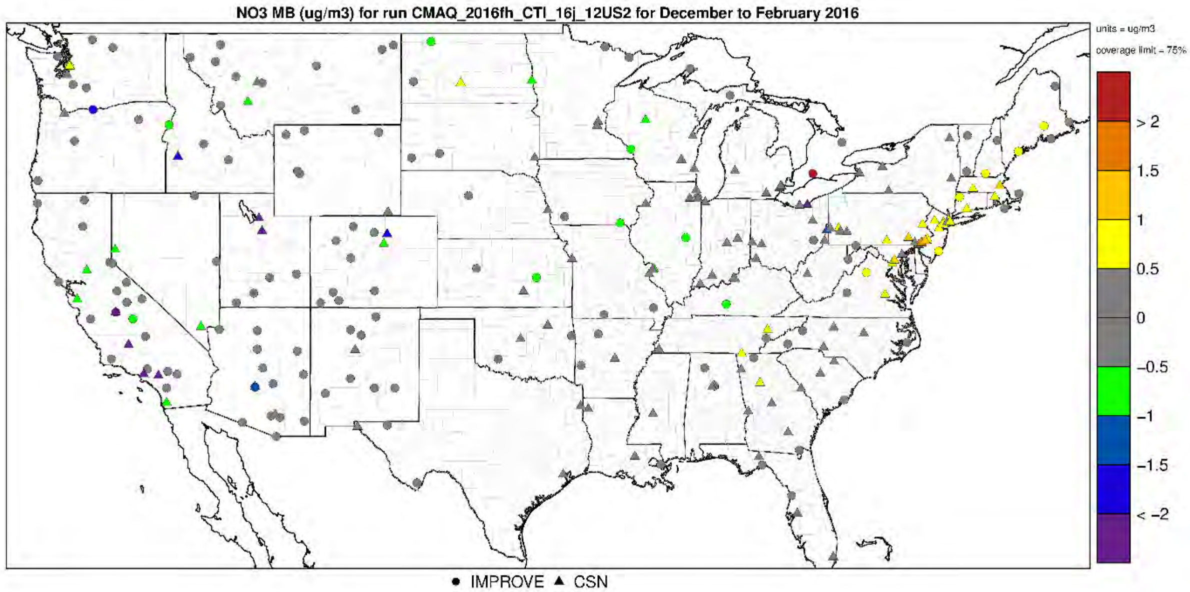

Figure 5-23 Mean Bias (ug/m^3) for nitrate during winter 2016 at monitoring sites in the modeling domain

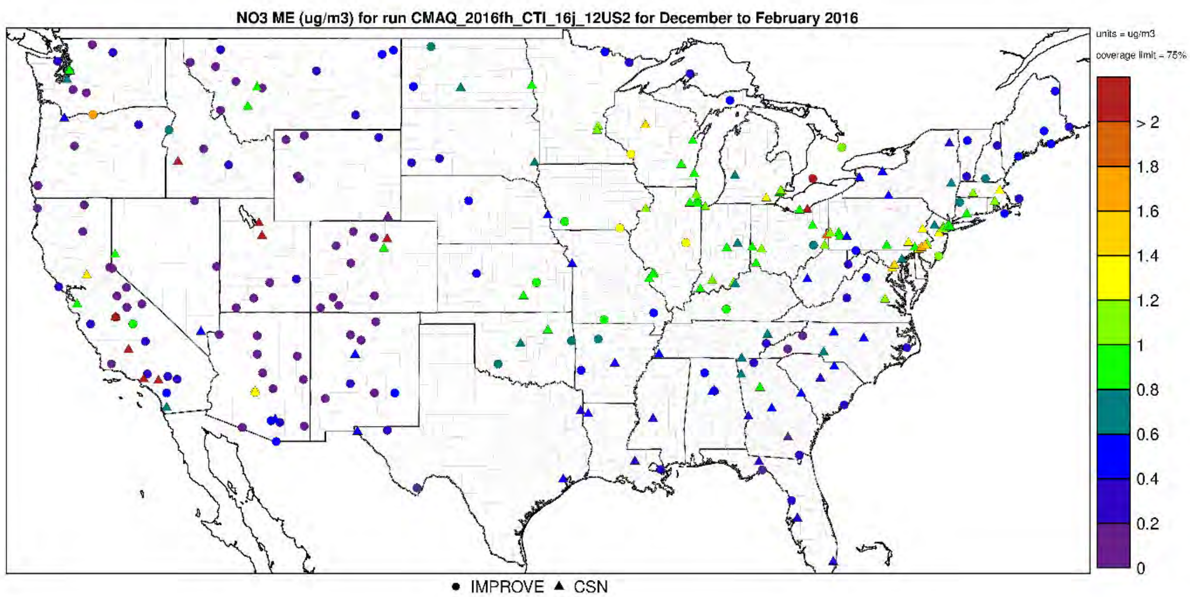

Figure 5-24 Mean Error (ug/m^3) for nitrate during winter 2016 at monitoring sites in the modeling domain

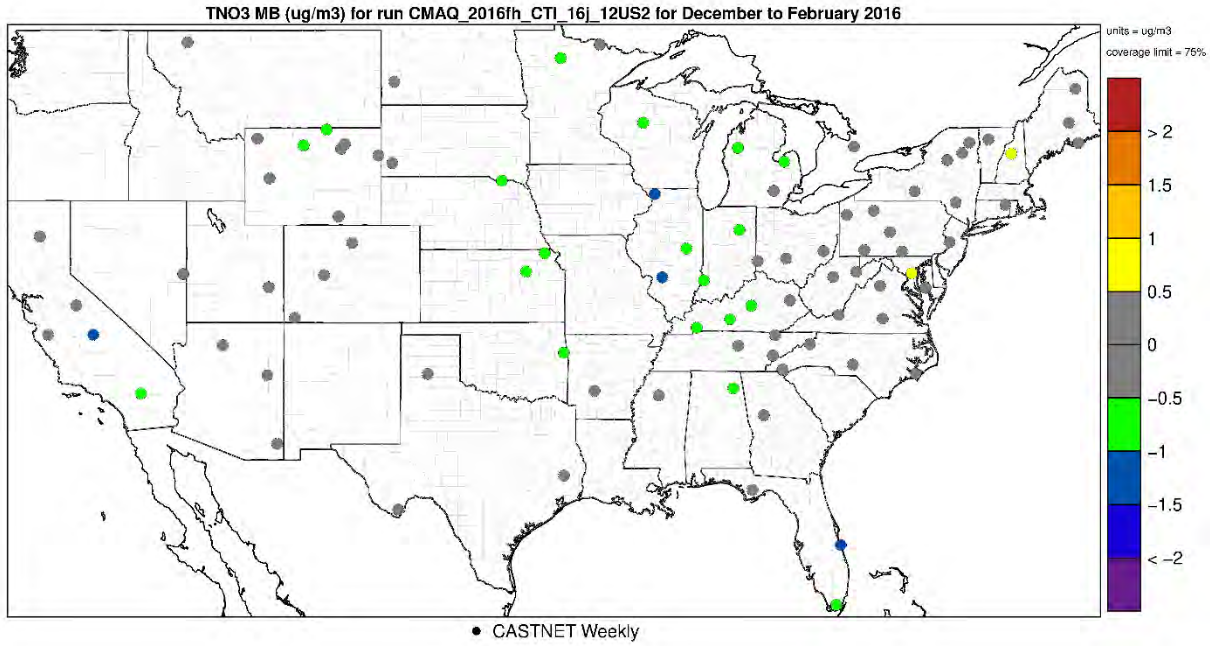

Figure 5-25 Mean Bias (ug/m^3) for total nitrate during winter 2016 at monitoring sites in the modeling domain

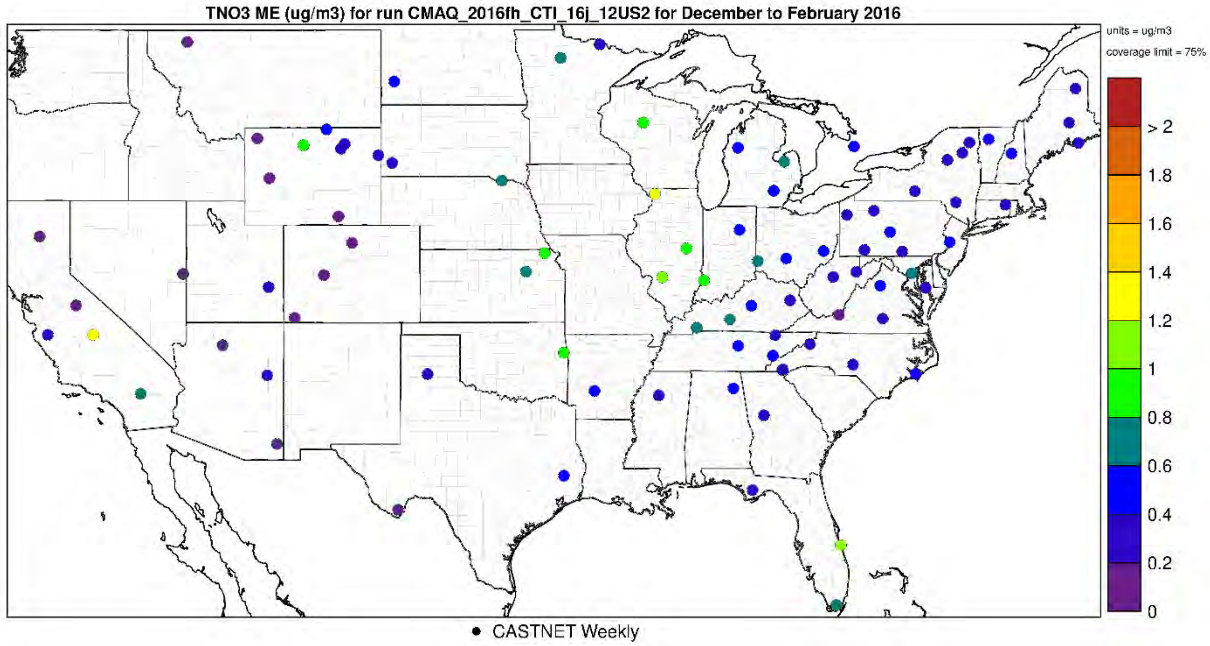

Figure 5-26 Mean Error (ug/m^3) for total nitrate during winter 2016 at monitoring sites in the modeling domain

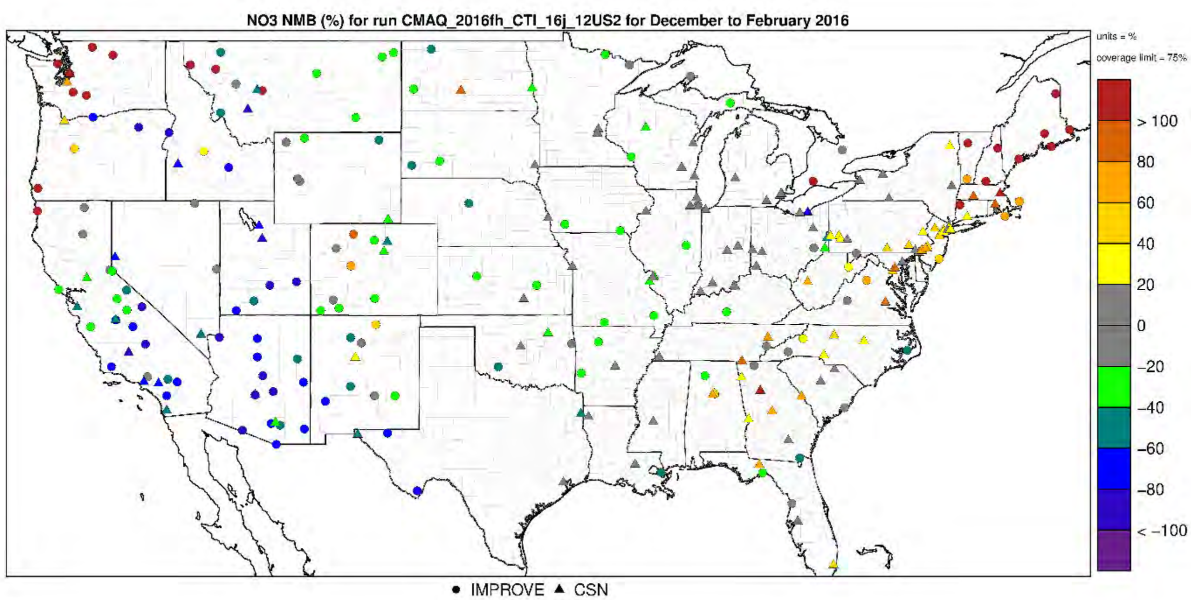

Figure 5-27 Normalized Mean Bias (%) for nitrate during winter 2016 at monitoring sites in the modeling domain

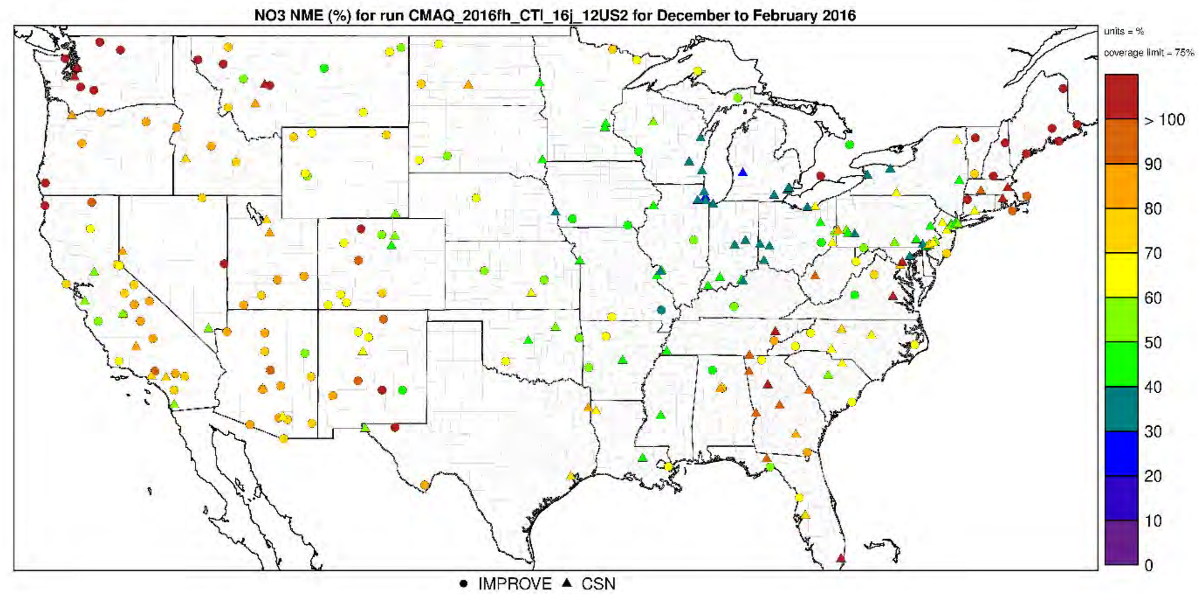

Figure 5-28 Normalized Mean Error (%) for nitrate during winter 2016 at monitoring sites in the modeling domain

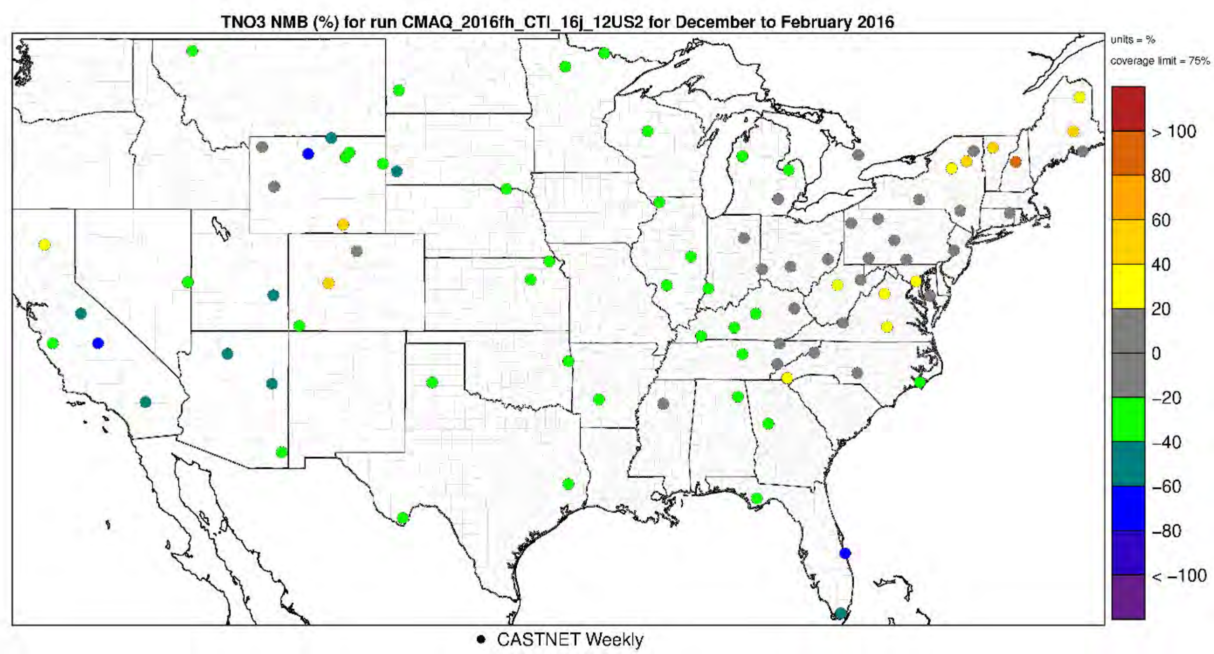

Figure 5-29 Normalized Mean Bias (%) for total nitrate during winter 2016 at monitoring sites in the modeling domain

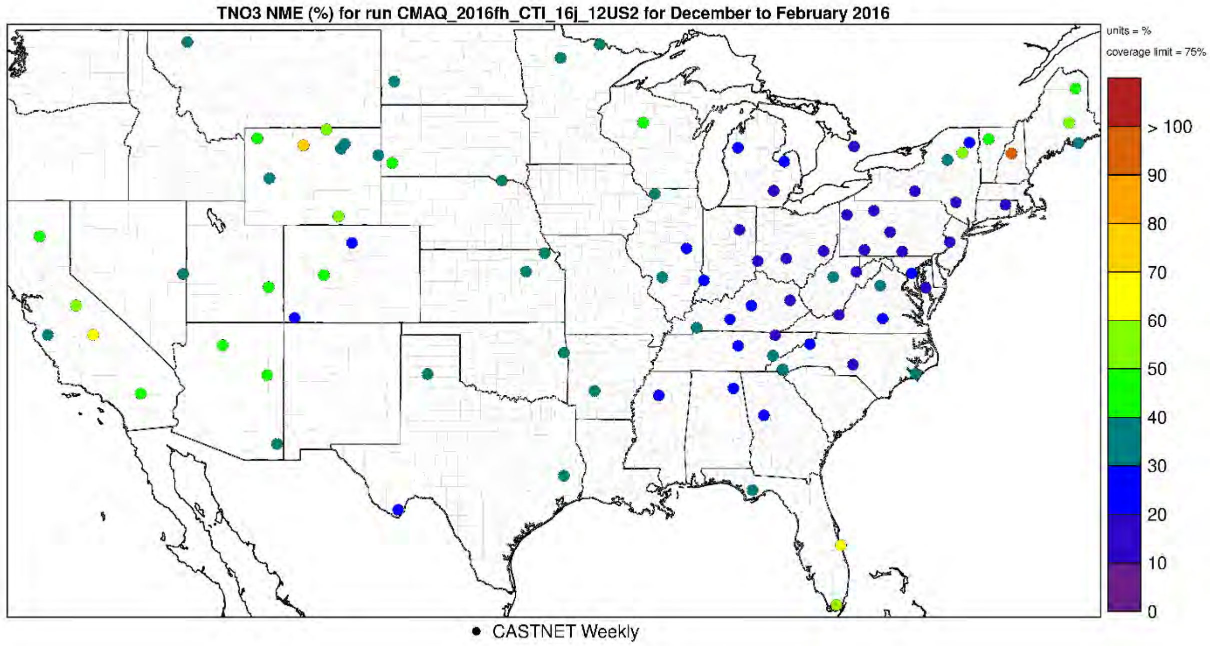

Figure 5-30 Normalized Mean Error (%) for total nitrate during winter 2016 at monitoring sites in the modeling domain

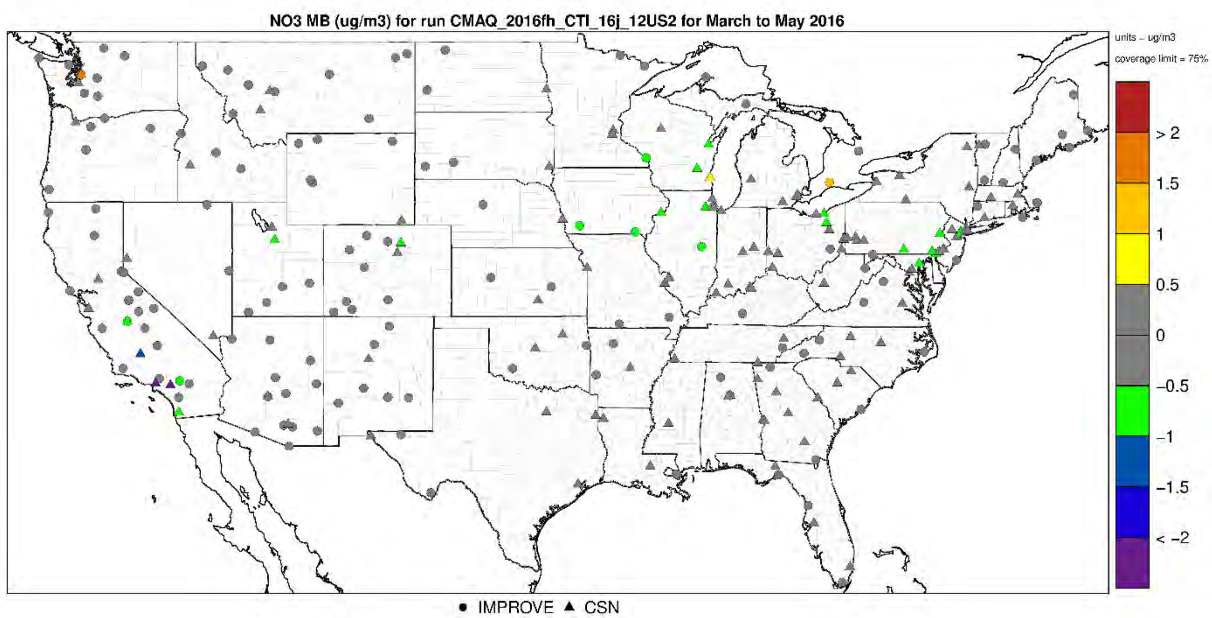

Figure 5-31 Mean Bias (ug/m^3) for nitrate during spring 2016 at monitoring sites in the modeling domain

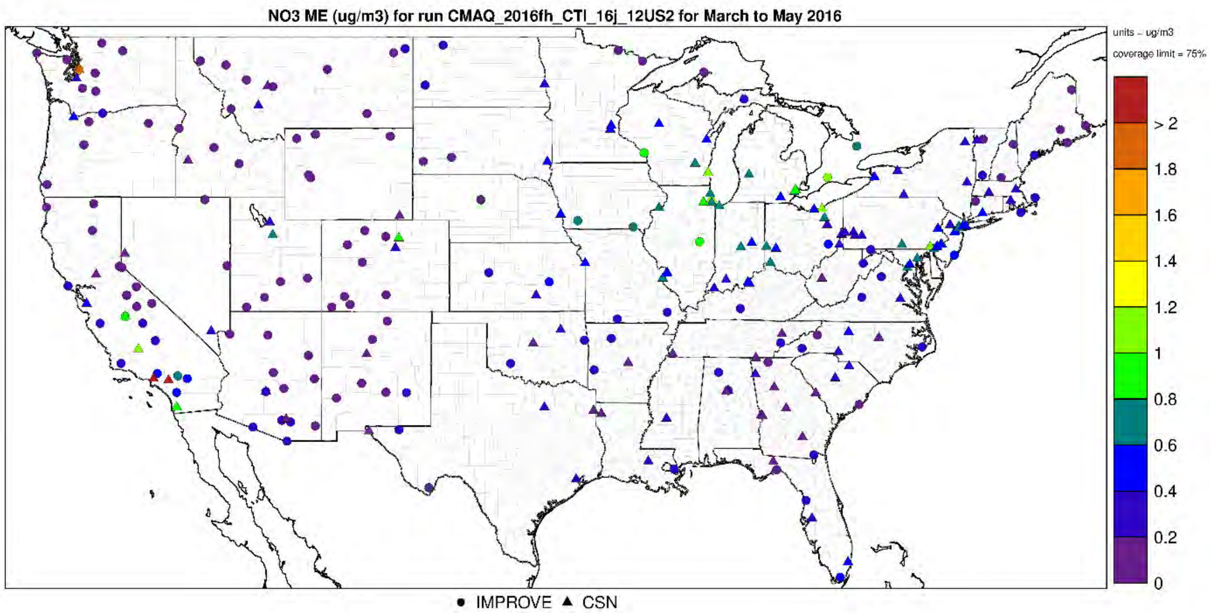

Figure 5-32 Mean Error (ug/m^3) for nitrate during spring 2016 at monitoring sites in the modeling domain

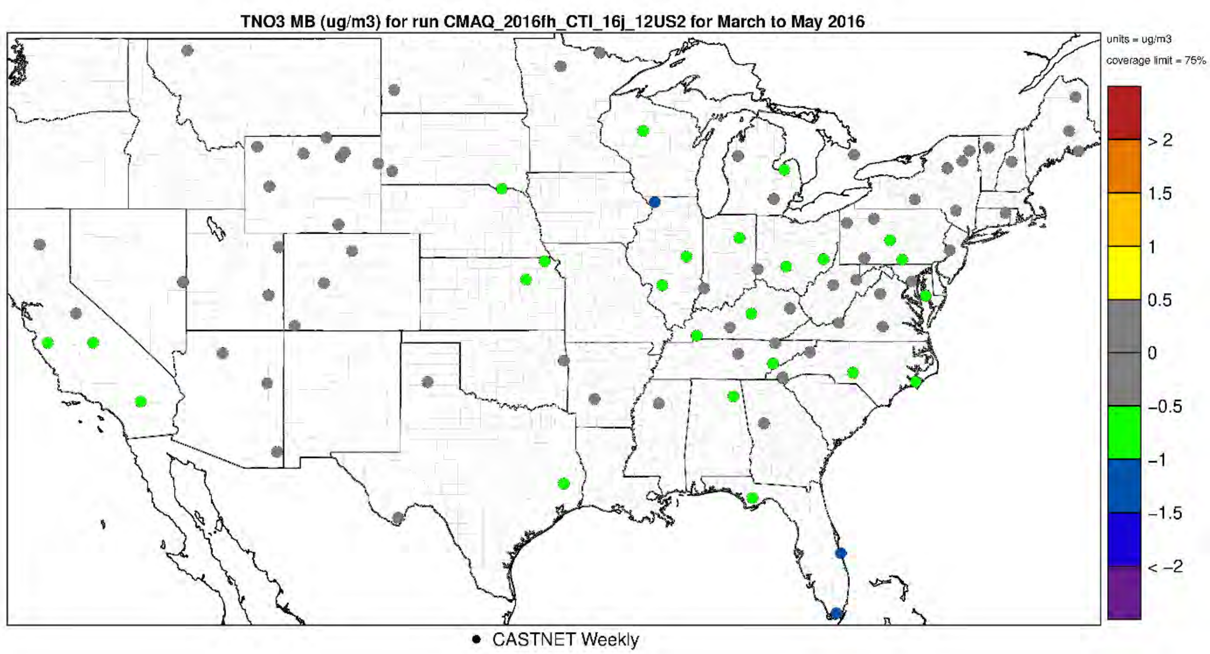

Figure 5-33 Mean Bias (ug/m^3) for total nitrate during spring 2016 at monitoring sites in the modeling domain

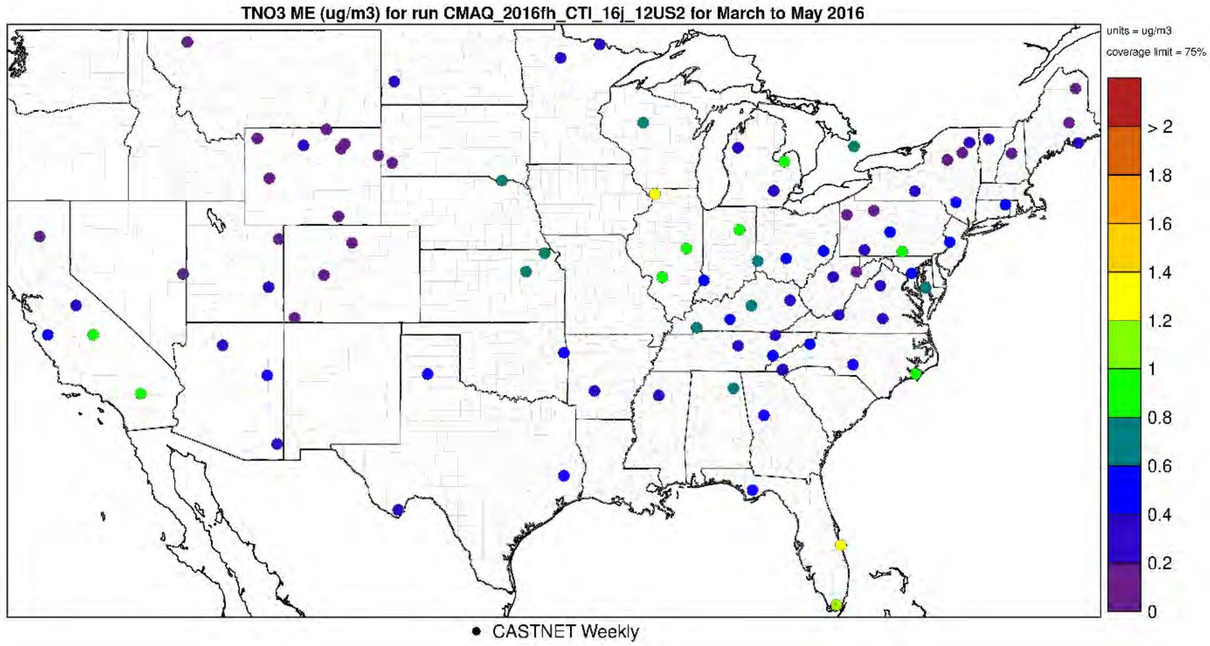

Figure 5-34 Mean Error (ug/m³) for total nitrate during spring 2016 at monitoring sites in the modeling domain

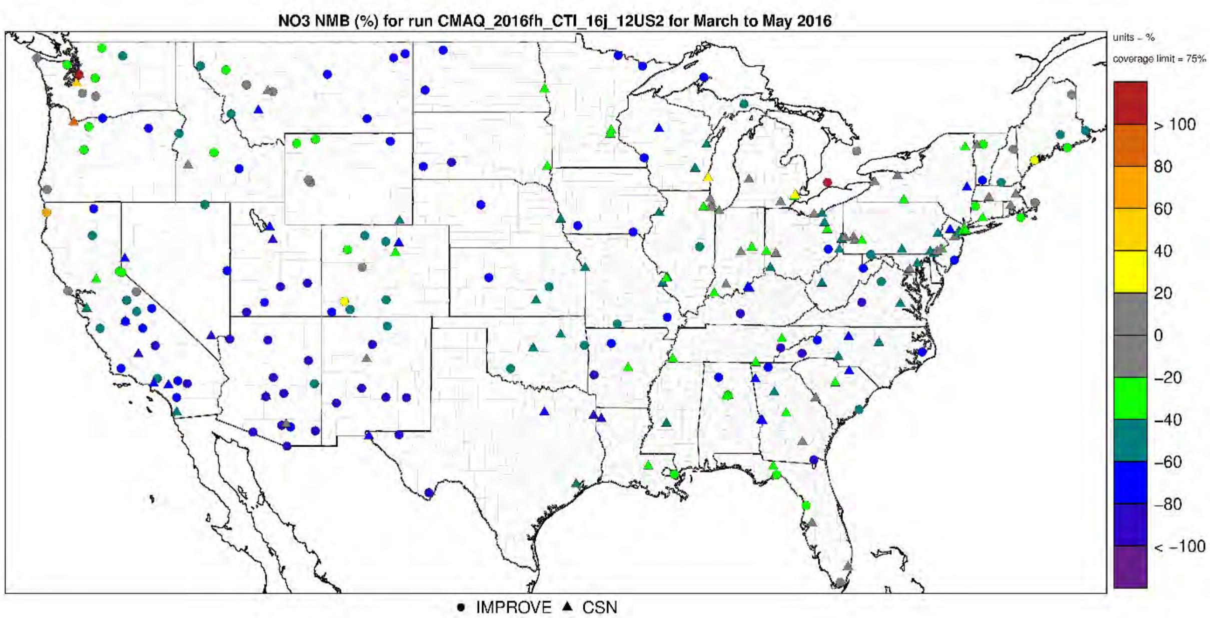

Figure 5-35 Normalized Mean Bias (%) for nitrate during spring 2016 at monitoring sites in the modeling domain

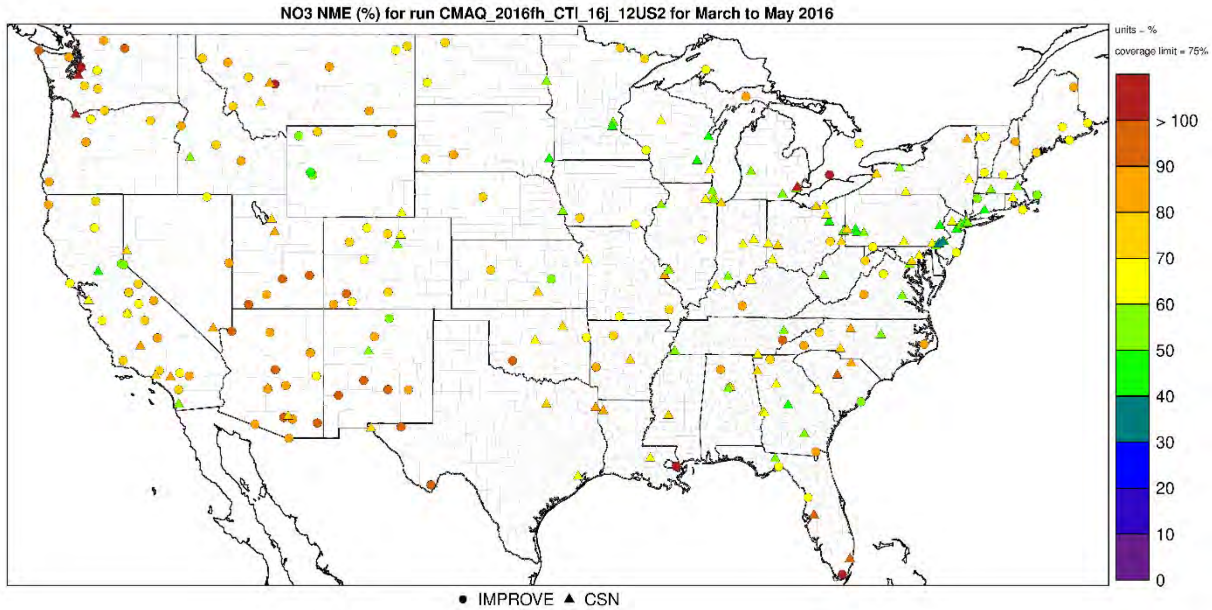

Figure 5-36 Normalized Mean Error (%) for nitrate during spring 2016 at monitoring sites in the modeling domain

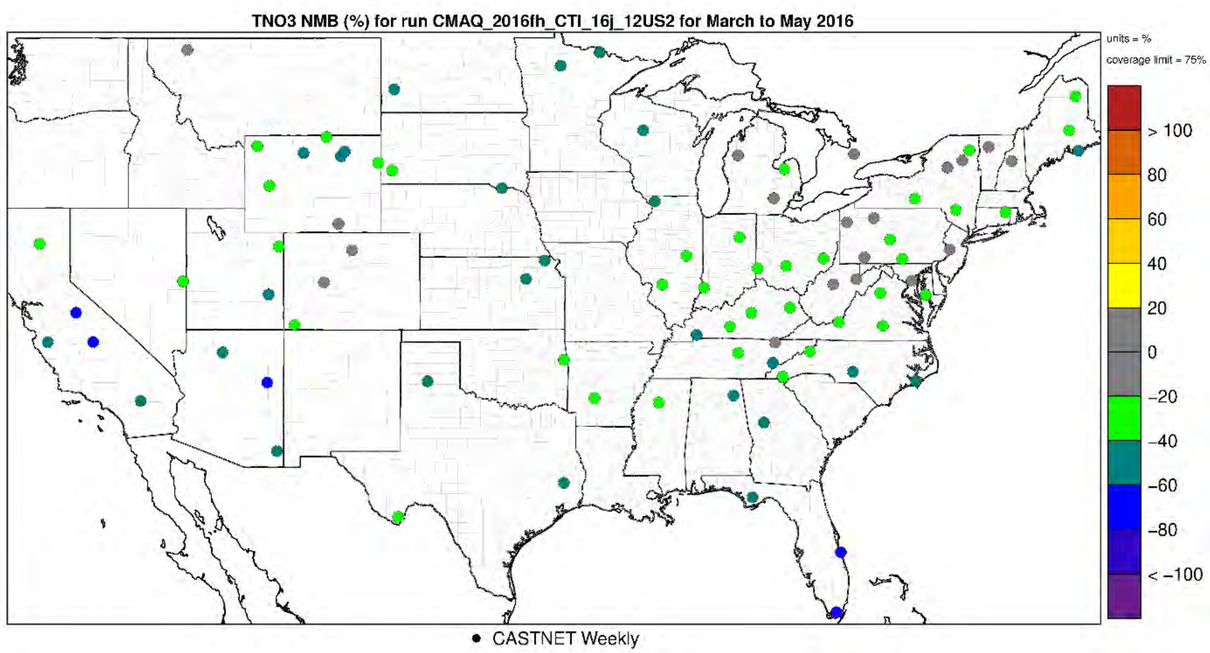

Figure 5-37 Normalized Mean Bias (%) for total nitrate during spring 2016 at monitoring sites in the modeling domain

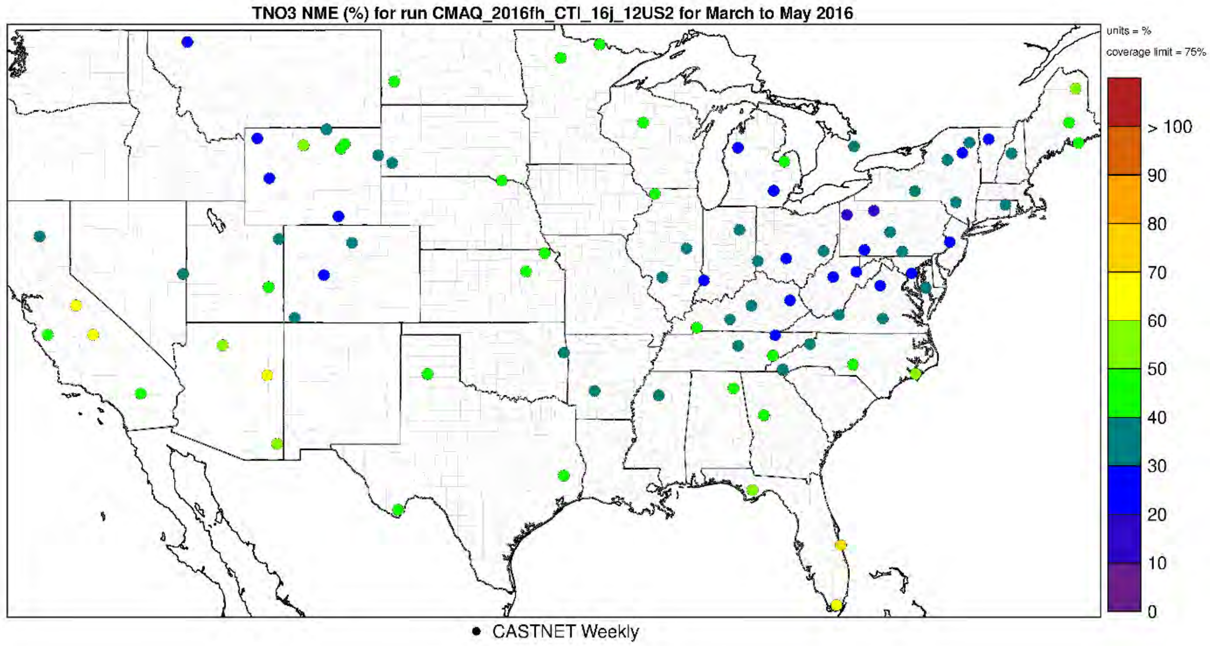

Figure 5-38 Normalized Mean Error (%) for total nitrate during spring 2016 at monitoring sites in the modeling domain

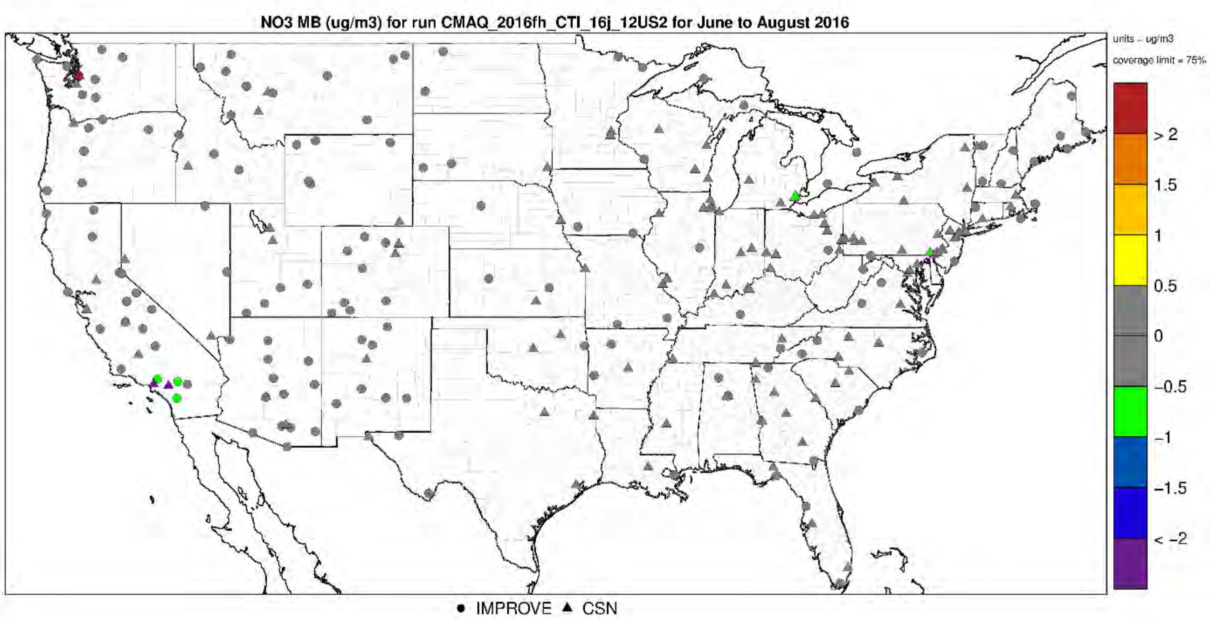

Figure 5-39 Mean Bias (ug/m^3) for nitrate during summer 2016 at monitoring sites in the modeling domain

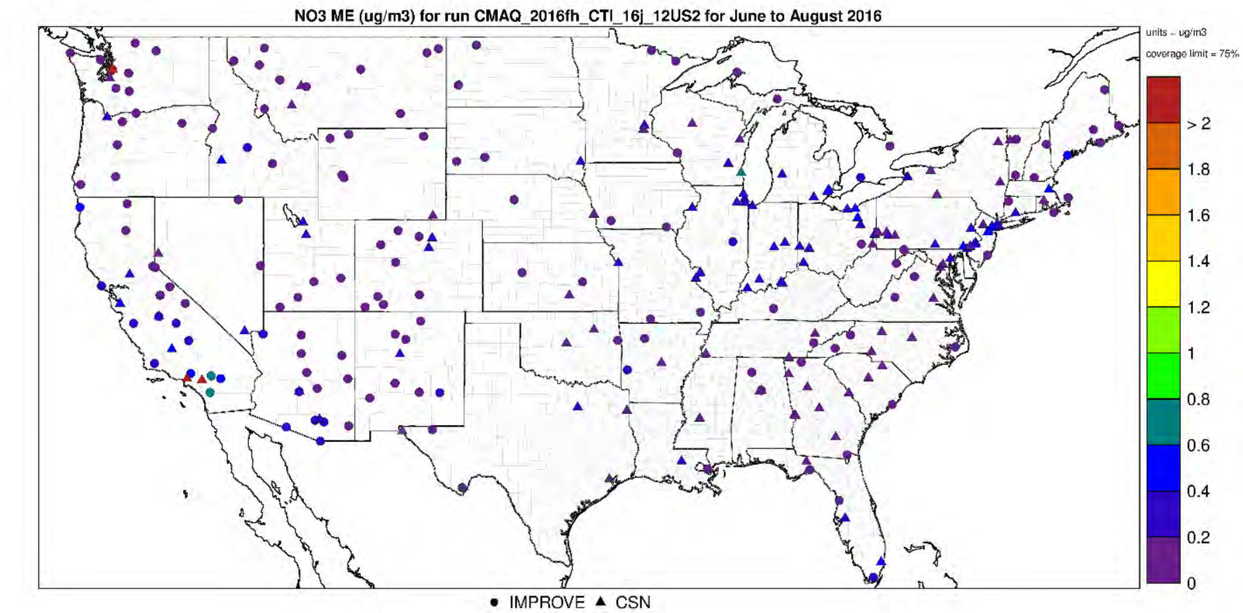

Figure 5-40 Mean Error (ug/m^3) for nitrate during summer 2016 at monitoring sites in the modeling domain

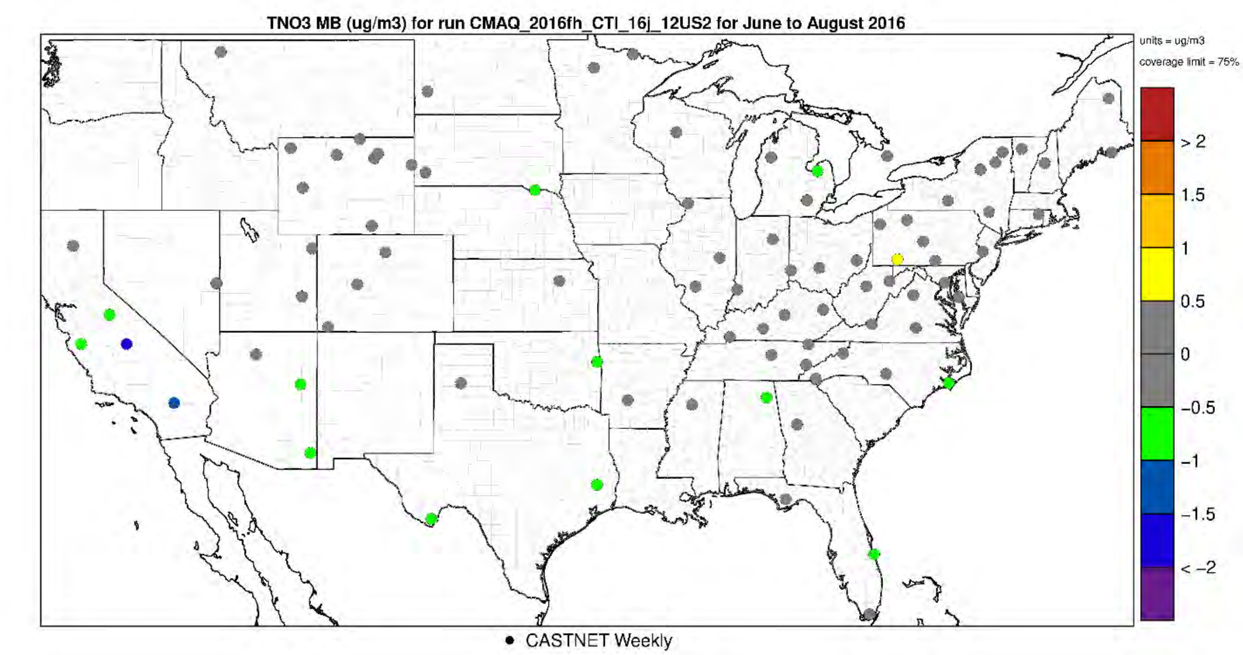

Figure 5-41 Mean Bias (ug/m3) for total nitrate during summer 2016 at monitoring sites in the modeling domain

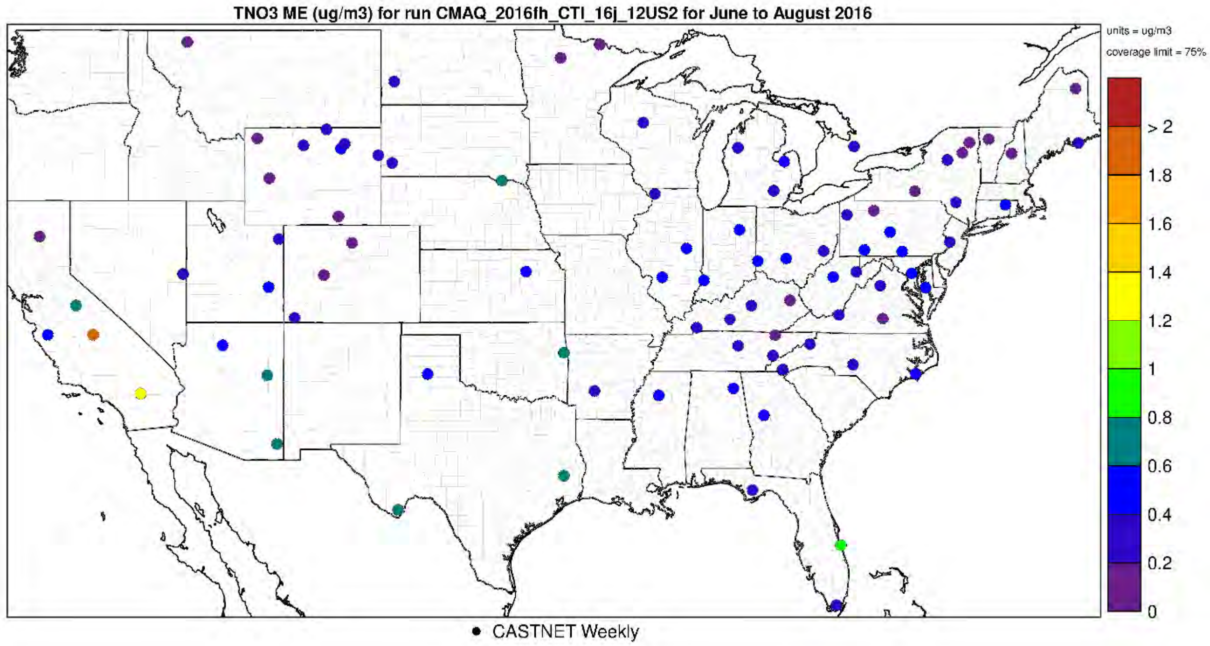

Figure 5-42 Mean Error (ug/m3) for total nitrate during summer 2016 at monitoring sites in the modeling domain

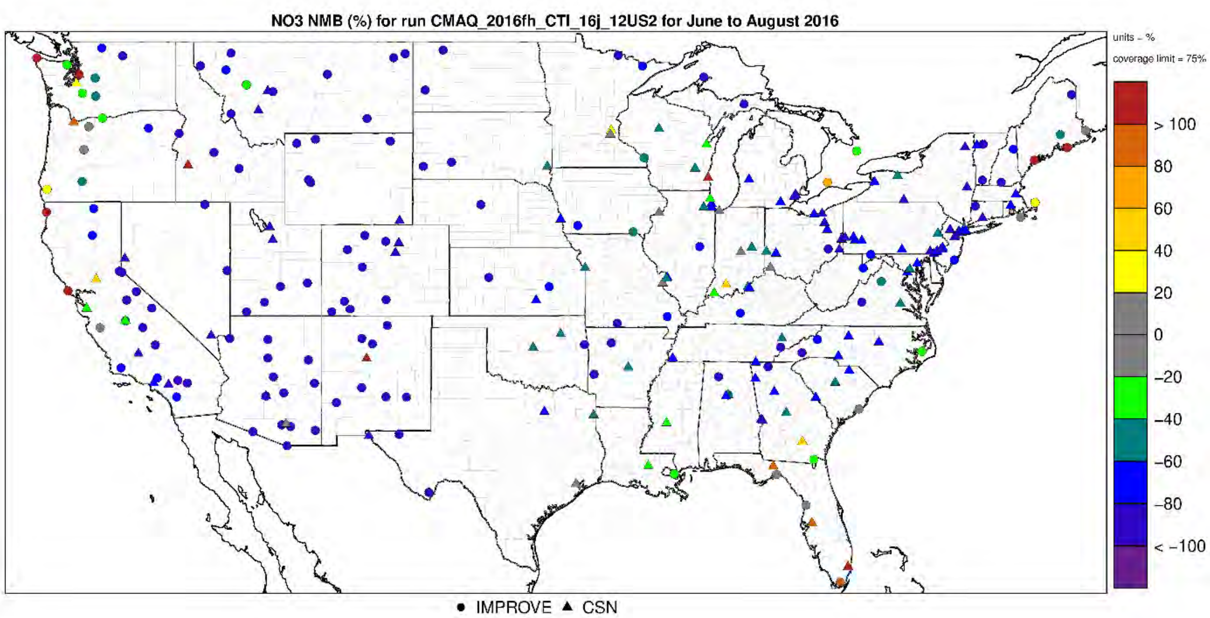

Figure 5-43 Normalized Mean Bias (%) for nitrate during summer 2016 at monitoring sites in the modeling domain

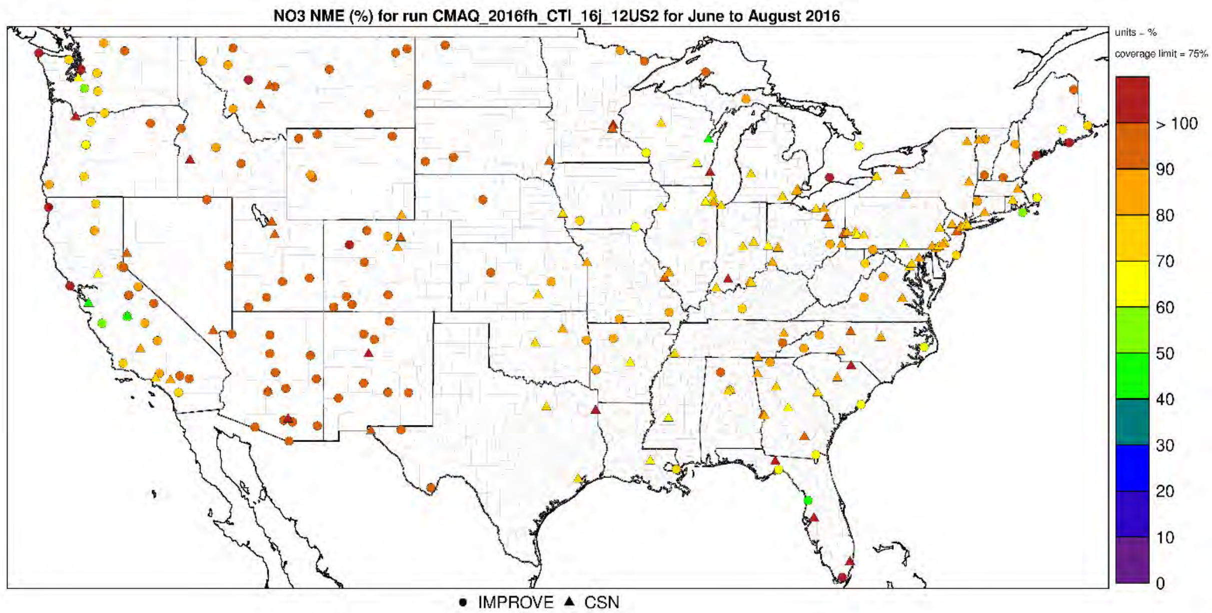

Figure 5-44 Normalized Mean Error (%) for nitrate during summer 2016 at monitoring sites in the modeling domain

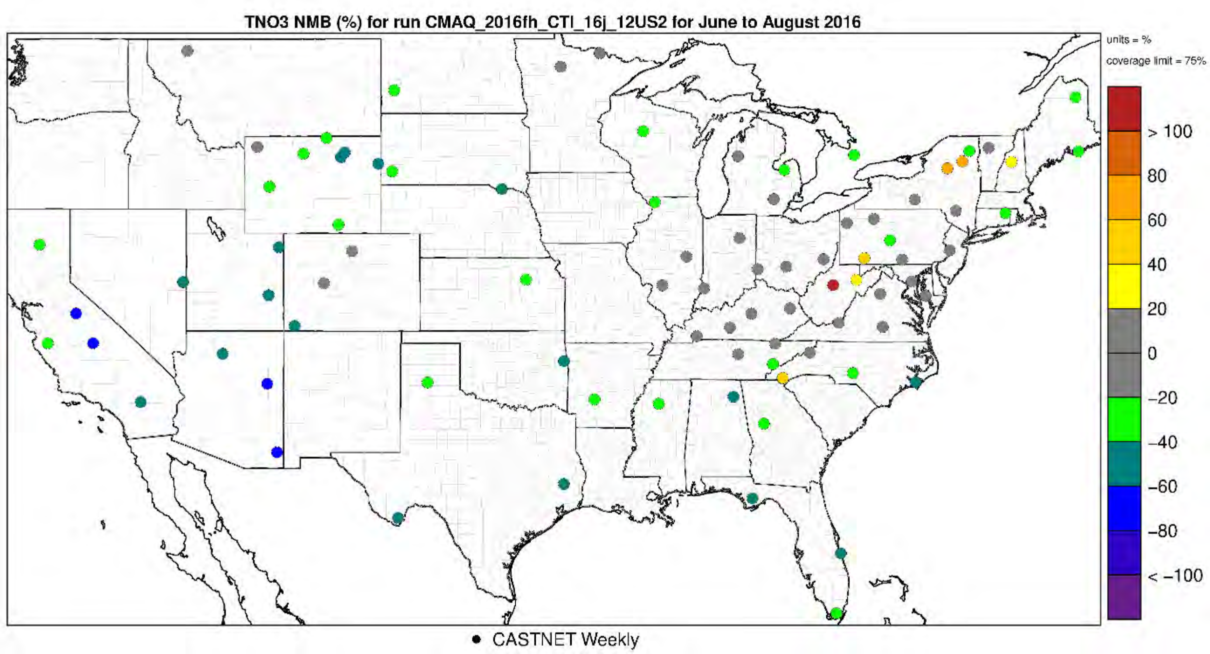

Figure 5-45 Normalized Mean Bias (%) for total nitrate during summer 2016 at monitoring sites in the modeling domain

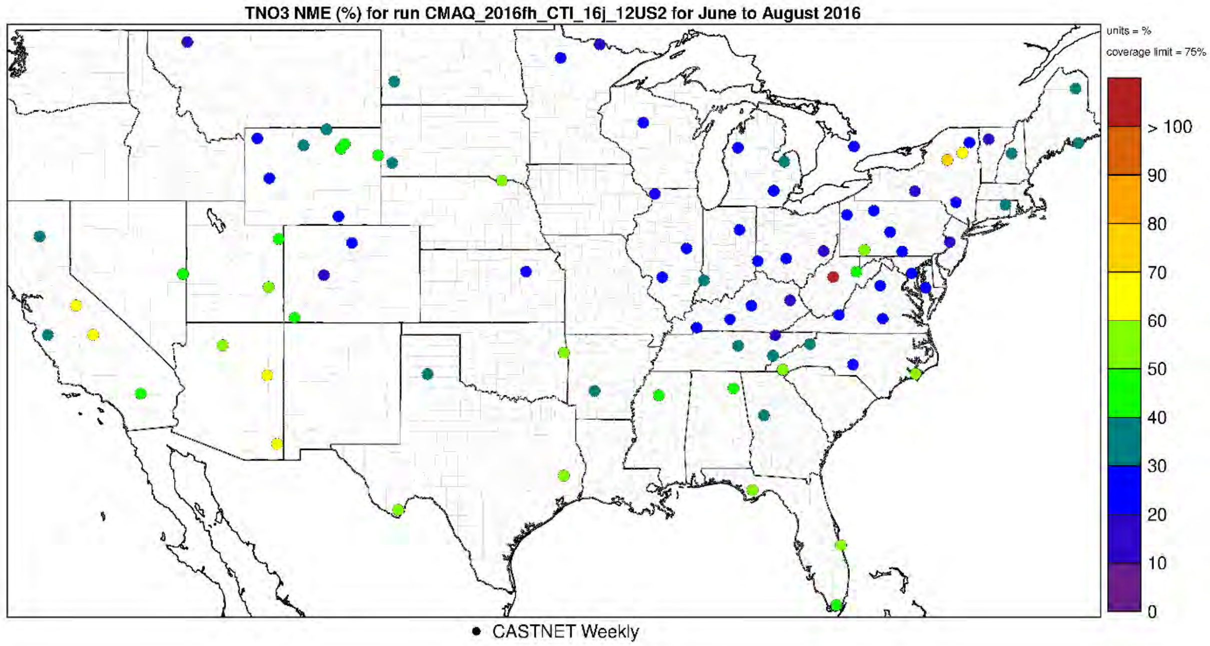

Figure 5-46 Normalized Mean Error (%) for total nitrate during summer 2016 at monitoring sites in the modeling domain

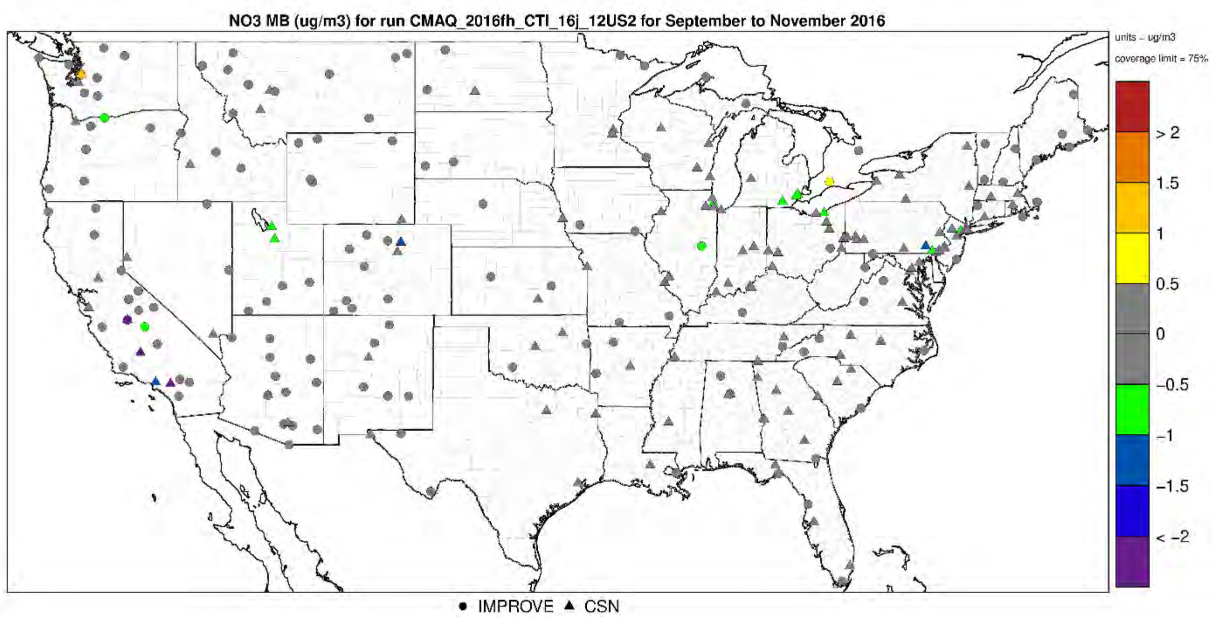

Figure 5-47 Mean Bias (ug/m^3) for nitrate during fall 2016 at monitoring sites in the modeling domain

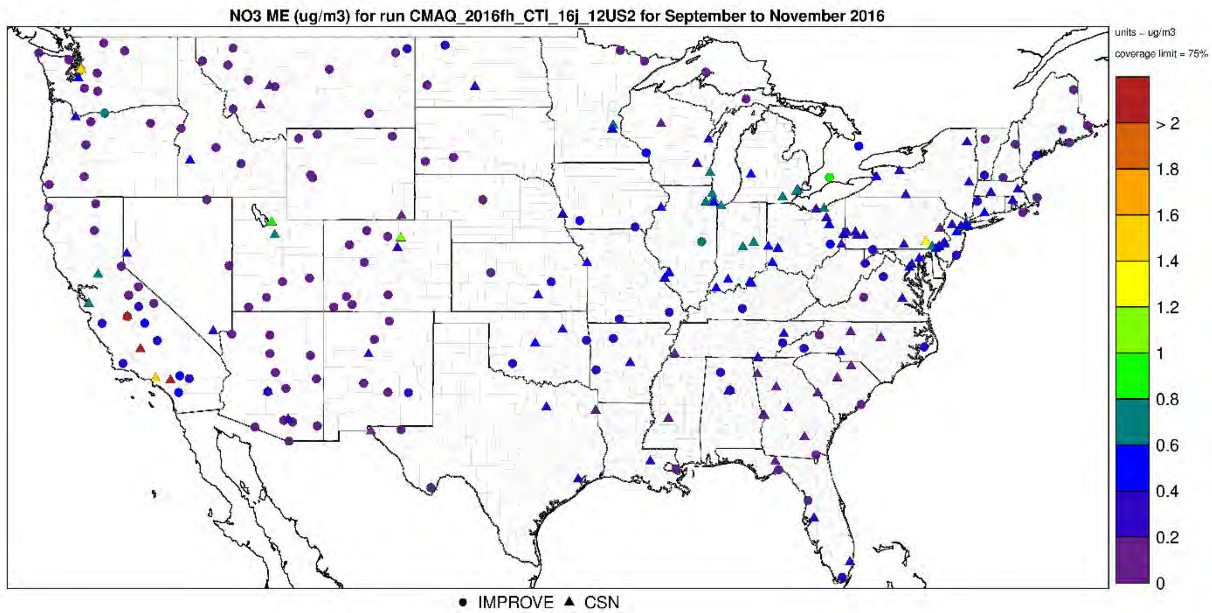

Figure 5-48 Mean Error (ug/m^3) for nitrate during fall 2016 at monitoring sites in the modeling domain

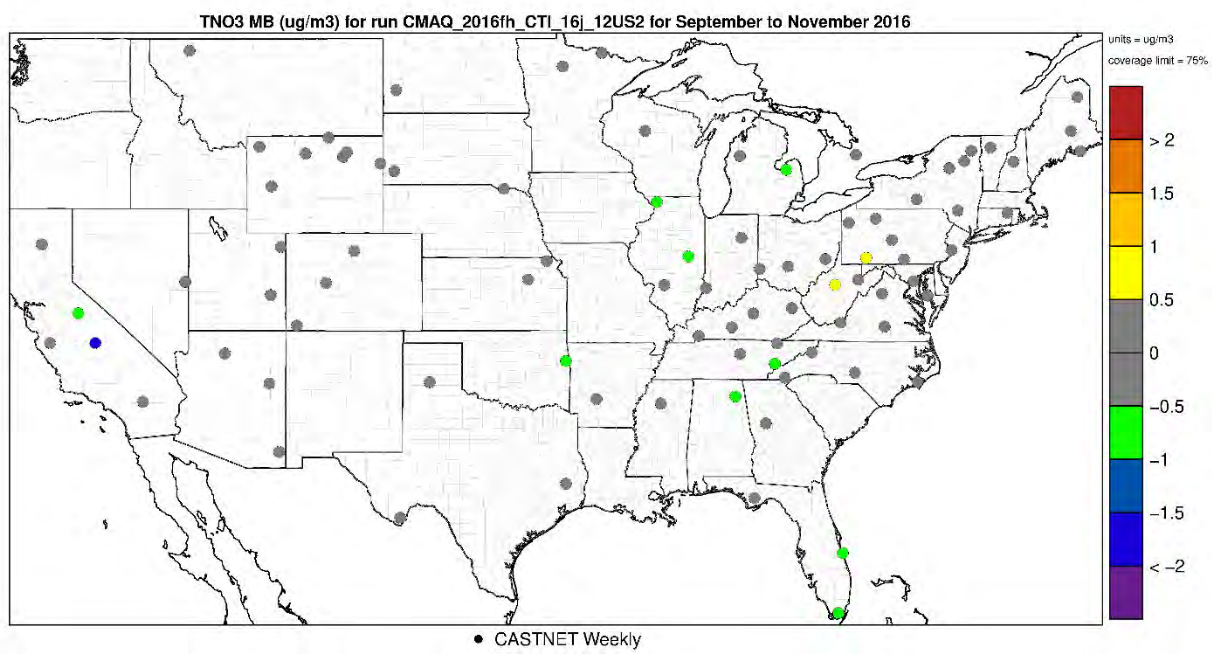

Figure 5-49 Mean Bias (ug/m^3) for total nitrate during fall 2016 at monitoring sites in the modeling domain

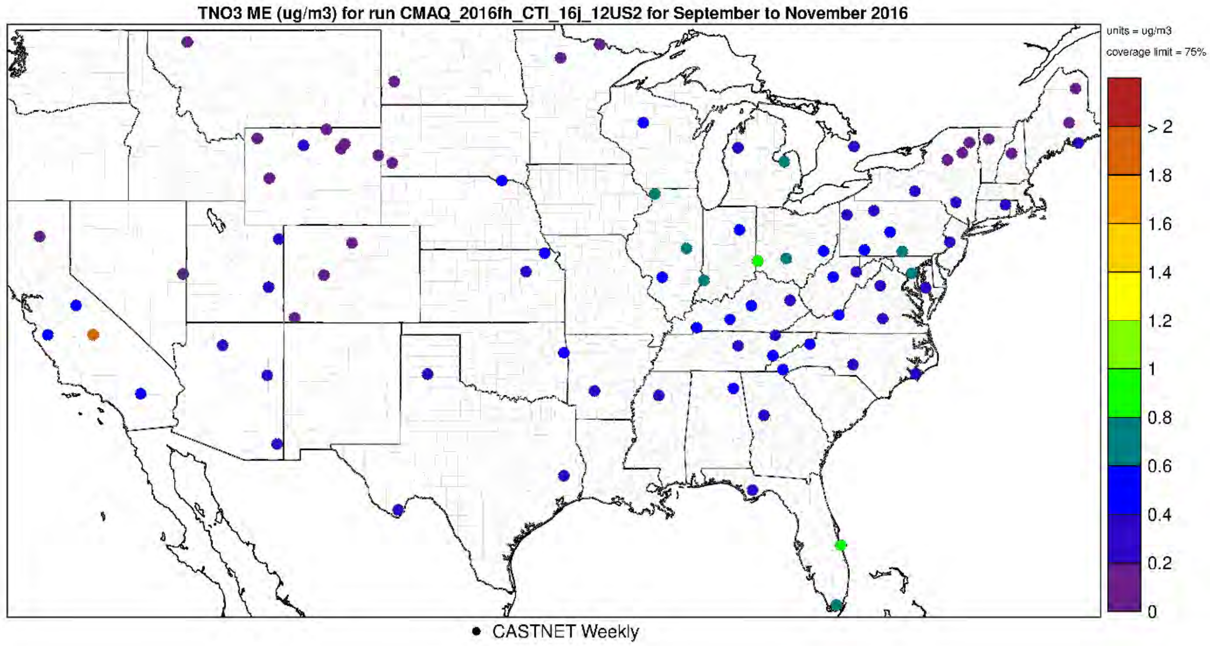

Figure 5-50 Mean Error (ug/m^3) for total nitrate during fall 2016 at monitoring sites in the modeling domain

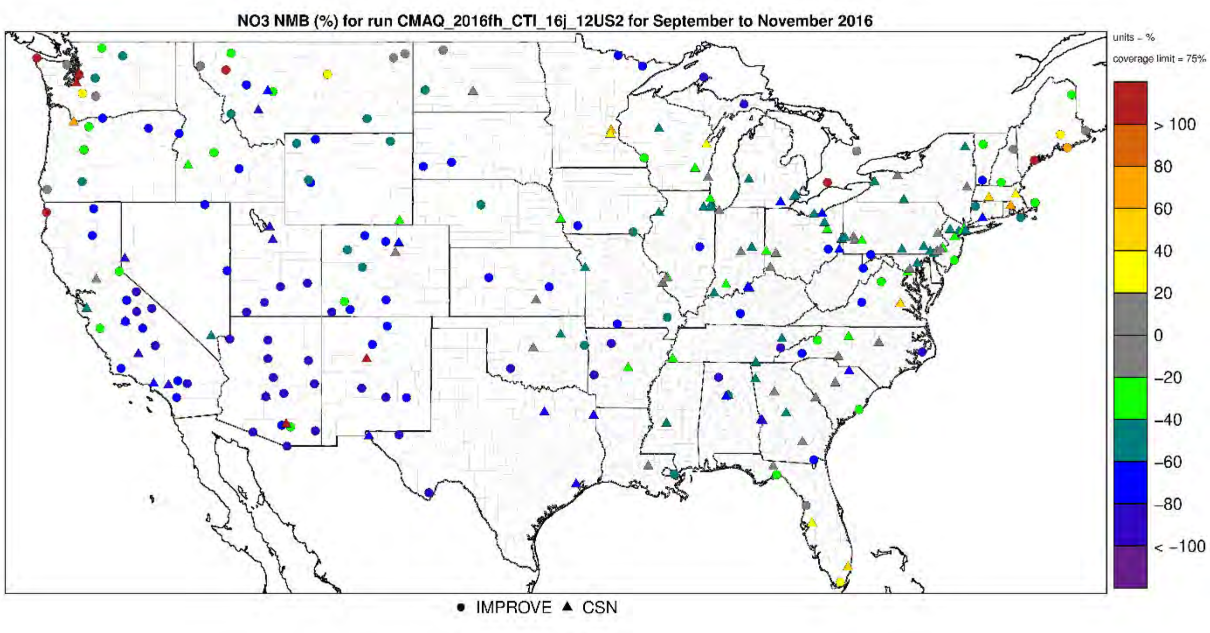

Figure 5-51 Normalized Mean Bias (%) for nitrate during fall 2016 at monitoring sites in the modeling domain

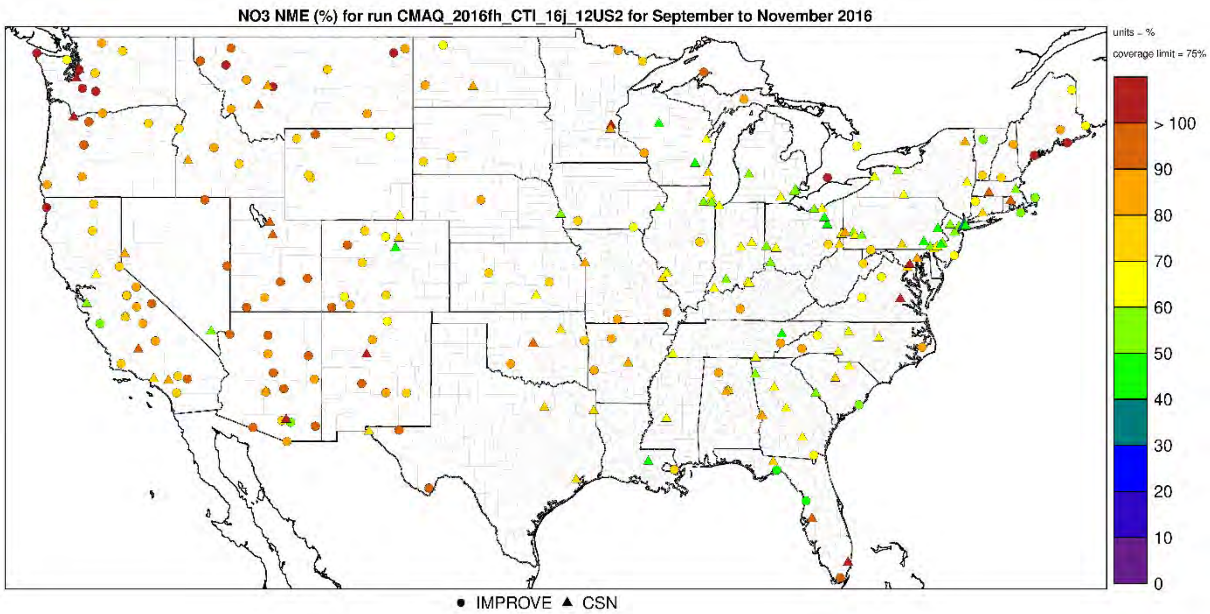

Figure 5-52 Normalized Mean Error (%) for nitrate during fall 2016 at monitoring sites in the modeling domain

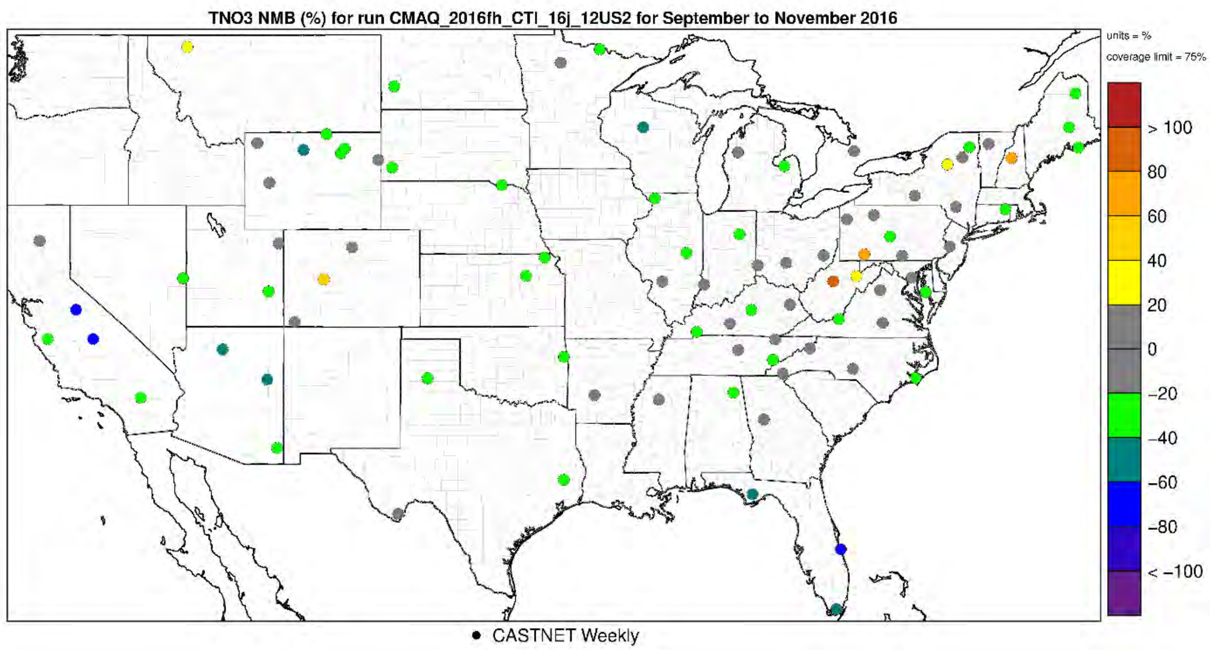

Figure 5-53 Normalized Mean Bias (%) for total nitrate during fall 2016 at monitoring sites in the modeling domain

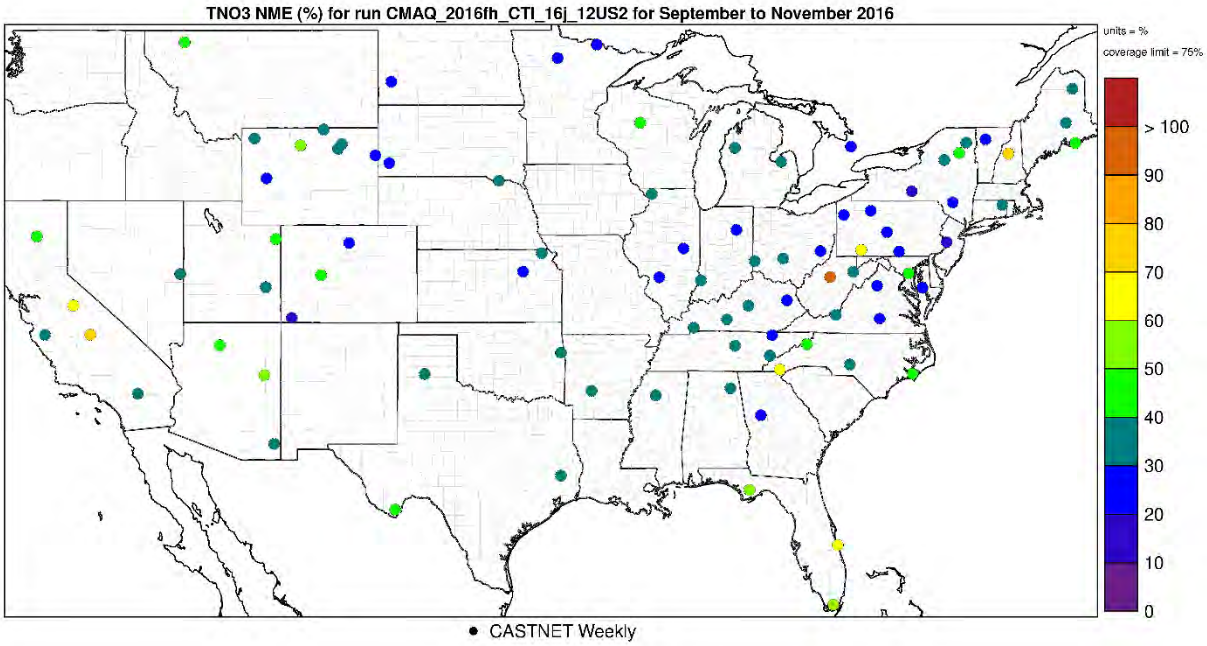

Figure 5-54 Normalized Mean Error (%) for total nitrate during fall 2016 at monitoring sites in the modeling domain

5.4.4.3 Seasonal Ammonium Performance

The model performance bias and error statistics for ammonium for each climate region and season are provided in Table 5-7. Spatial plots of the mean bias and error as well as normalized mean bias and error by season for individual monitors are shown in Figure 5-55 through Figure 5-70.

Table 5-7 Ammonium Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2016 CMAQ Model Simulation

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	CSN	Winter	723	0.4	0.5	85.1	>100
		Spring	770	0.1	0.2	31.3	79.4
		Summer	755	0.0	0.1	-18.2	59.2
		Fall	729	0.0	0.2	14.5	78.9
	CASTNet	Winter	221	0.0	0.1	-4.5	24.5
		Spring	242	-0.1	0.2	-38.1	39.6
		Summer	239	-0.2	0.2	-46.4	46.4
		Fall	237	-0.1	0.2	-46.9	47.7

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Ohio Valley	CSN	Winter	519	0.1	0.5	16.7	57.2
		Spring	531	0.0	0.2	12.2	67.8
		Summer	523	0.0	0.2	-7.4	59.0
		Fall	511	-0.1	0.2	-17.4	62.8
	CASTNet	Winter	212	-0.3	0.3	-30.1	32.3
		Spring	228	-0.3	0.3	-48.6	48.9
		Summer	224	-0.2	0.3	-45.1	45.9
		Fall	226	-0.3	0.3	-53.2	53.2
Upper Midwest	CSN	Winter	298	0.3	0.5	37.4	61.9
		Spring	323	0.1	0.3	18.8	70.0
		Summer	285	0.0	0.2	19.5	79.9
		Fall	280	0.1	0.2	40.6	98.2
	CASTNet	Winter	71	-0.3	0.3	-30.7	34.7
		Spring	76	-0.1	0.2	-28.7	38.7
		Summer	76	-0.1	0.1	-45.3	45.7
		Fall	70	-0.2	0.2	-49.9	51.0
Southeast	CSN	Winter	483	0.1	0.2	48.9	80.0
		Spring	522	-0.1	0.2	-36.3	58.9
		Summer	493	-0.1	0.2	-42.0	66.1
		Fall	473	-0.1	0.2	-28.9	67.0
	CASTNet	Winter	150	-0.1	0.1	-26.8	33.7
		Spring	164	-0.2	0.2	-58.2	58.3
		Summer	164	-0.2	0.2	-59.8	59.8
		Fall	154	-0.2	0.2	-55.6	56.3
South	CSN	Winter	273	0.1	0.2	40.9	79.8
		Spring	287	-0.1	0.2	-24.5	74.1
		Summer	279	-0.1	0.2	-24.1	79.1
		Fall	271	0.0	0.2	-13.6	60.5
	CASTNet	Winter	92	-0.2	0.2	-30.8	38.8

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Spring	102	-0.2	0.2	-53.9	56.3
		Summer	96	-0.2	0.2	-57.9	58.6
		Fall	102	-0.2	0.2	-46.8	48.8
Southwest	CSN	Winter	241	-0.4	0.6	-63.6	85.9
		Spring	255	0.0	0.1	-30.5	>100
		Summer	249	-0.1	0.1	-57.4	>100
		Fall	246	-0.1	0.2	-49.2	>100
	CASTNet	Winter	101	-0.1	0.1	-51.7	61.5
		Spring	115	-0.1	0.1	-44.5	50.3
		Summer	114	-0.1	0.1	-63.9	63.9
		Fall	115	-0.1	0.1	-52.9	54.3
Northern Rockies	CSN	Winter	141	0.2	0.3	85.4	>100
		Spring	145	0.1	0.1	66.5	>100
		Summer	135	0.1	0.1	89.9	>100
		Fall	139	0.1	0.1	138.0	>100
	CASTNet	Winter	138	-0.1	0.1	-44.0	46.7
		Spring	152	-0.1	0.1	-48.6	51.2
		Summer	151	-0.1	0.1	-58.2	58.3
		Fall	142	-0.1	0.1	-45.4	49.8
Northwest	CSN	Winter	142	0.0	0.3	10.0	>100
		Spring	146	0.1	0.2	>100	>100
		Summer	153	0.2	0.2	>100	>100
		Fall	146	0.1	0.2	96.3	>100
	CASTNet	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-
West	CSN	Winter	331	-0.5	0.7	-62.9	78.8
		Spring	351	-0.3	0.4	-75.2	87.6

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Summer	325	-0.4	0.4	-87.8	92.6
		Fall	319	-0.4	0.5	-78.2	89.6
	CASTNet	Winter	69	-0.1	0.1	-57.0	64.9
		Spring	73	-0.1	0.1	-70.5	71.2
		Summer	75	-0.3	0.3	-85.6	85.6
		Fall	77	-0.2	0.2	-68.9	69.5

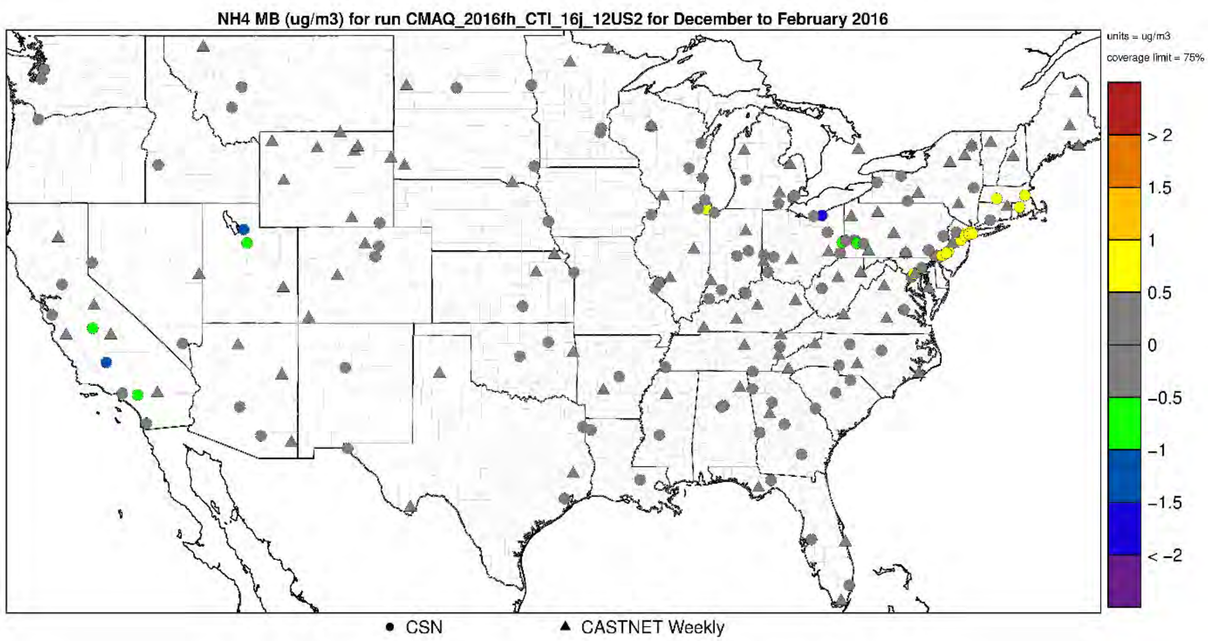

Figure 5-55 Mean Bias (ug/m3) of ammonium during winter 2016 at monitoring sites in the modeling domain

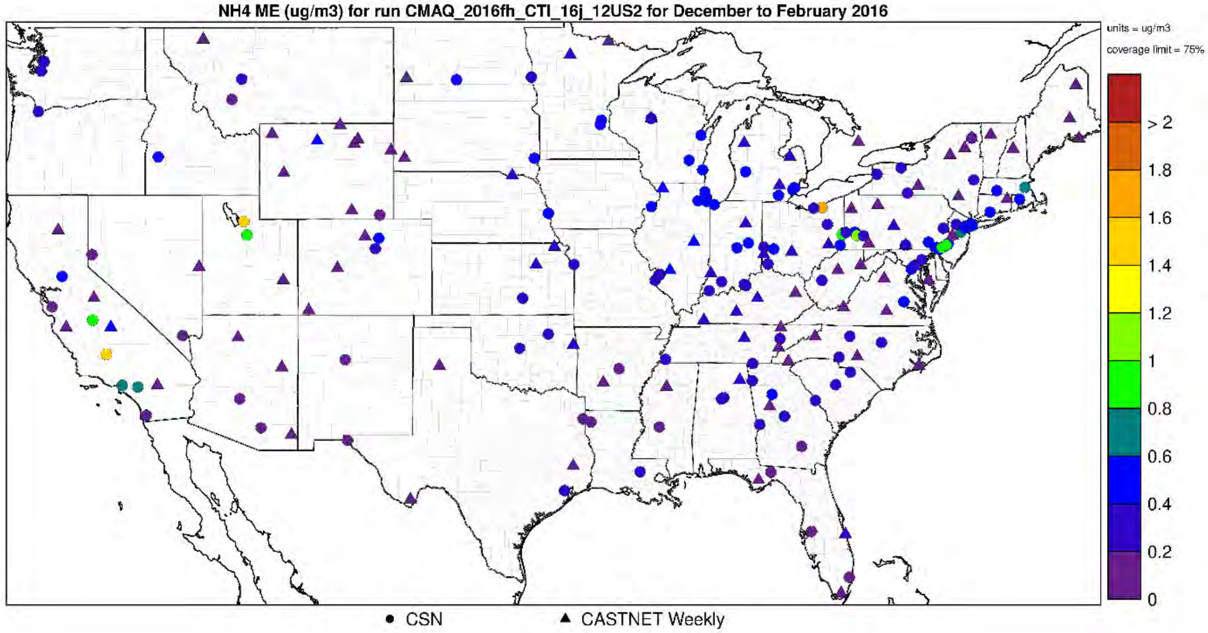

Figure 5-56 Mean Error (ug/m3) of ammonium during winter 2016 at monitoring sites in the modeling domain

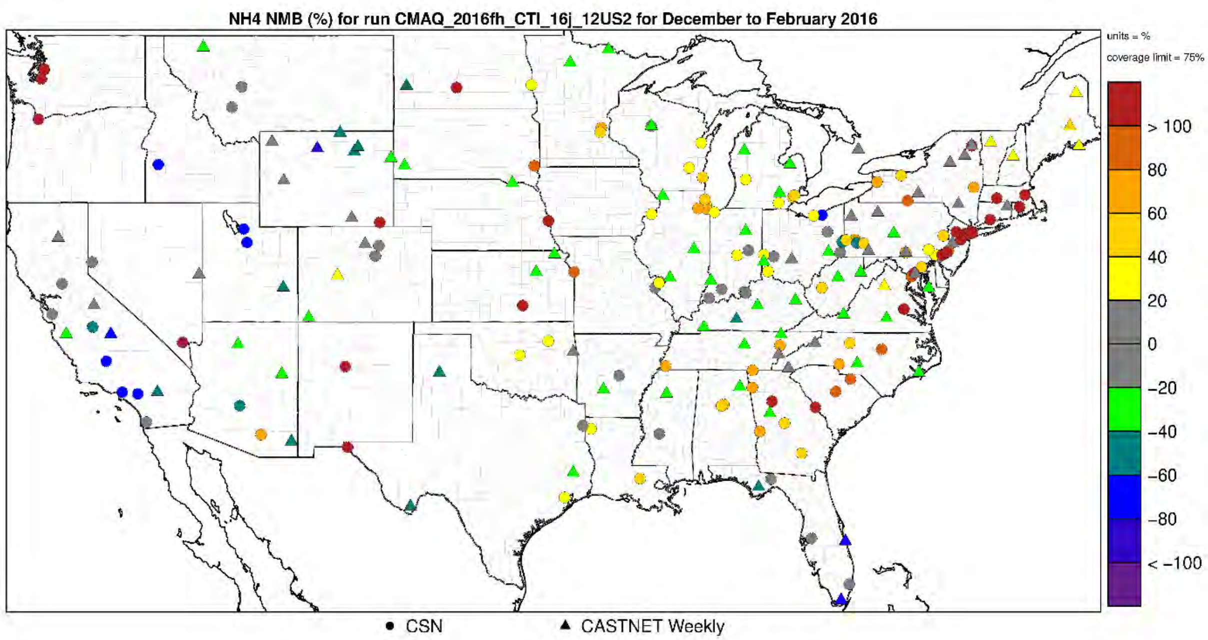

Figure 5-57 Normalized Mean Bias (%) of ammonium during winter 2016 at monitoring sites in the modeling domain

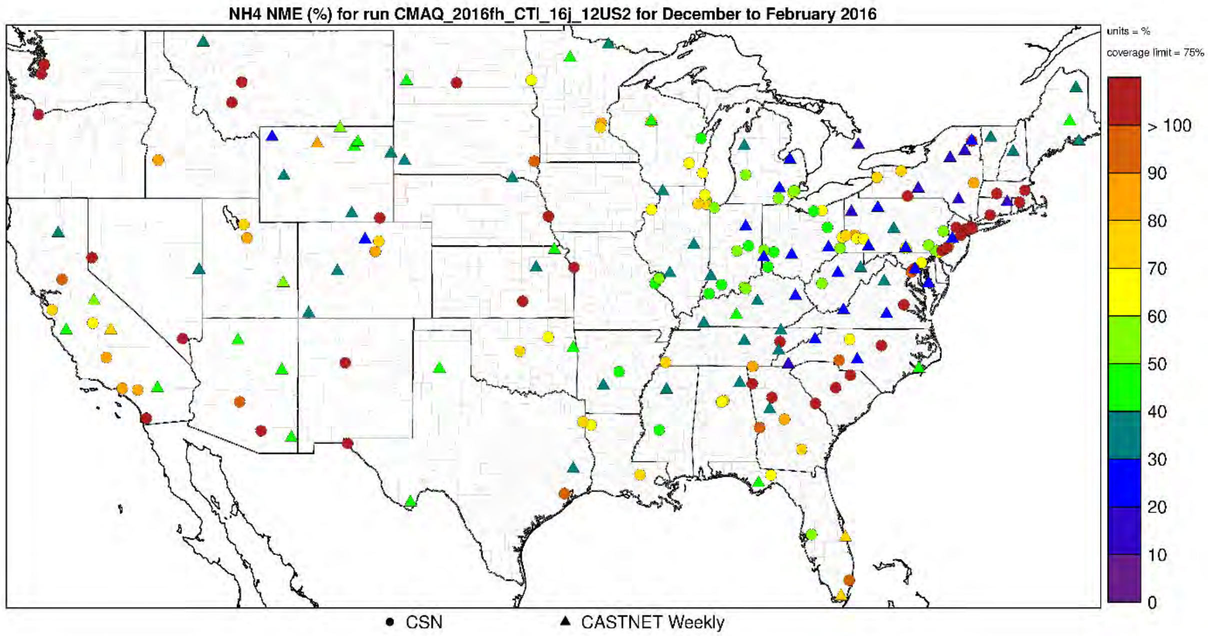

Figure 5-58 Normalized Mean Error (%) of ammonium during winter 2016 at monitoring sites in the modeling domain

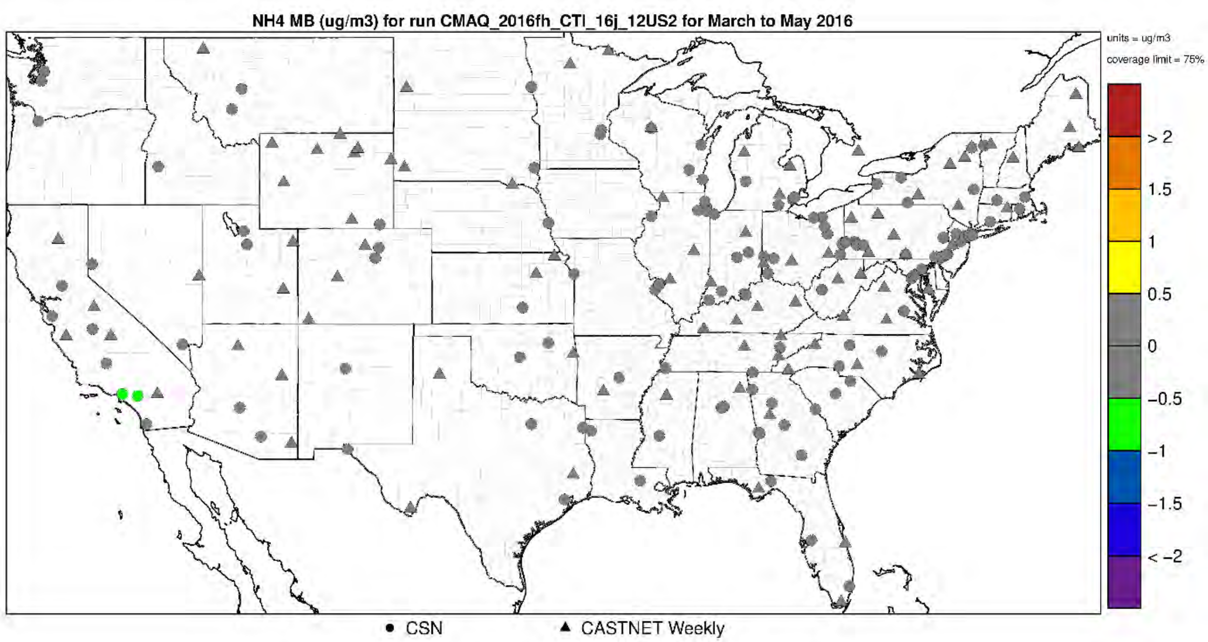

Figure 5-59 Mean Bias (ug/m^3) of ammonium during spring 2016 at monitoring sites in the modeling domain

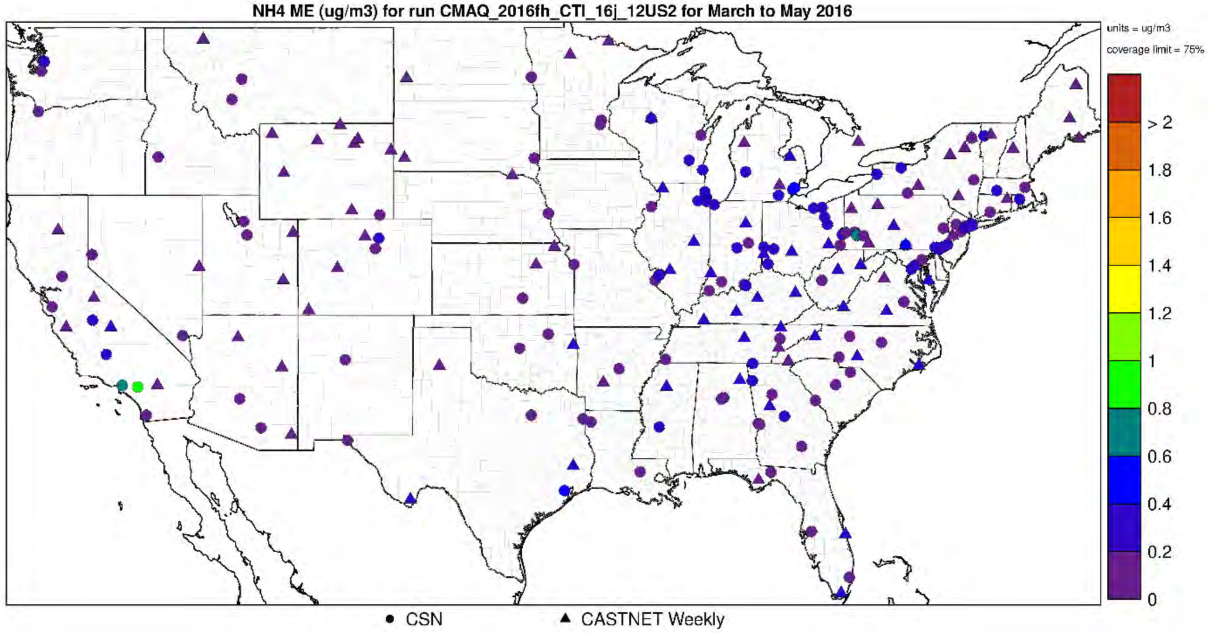

Figure 5-60 Mean Error (ug/m³) of ammonium during spring 2016 at monitoring sites in the modeling domain

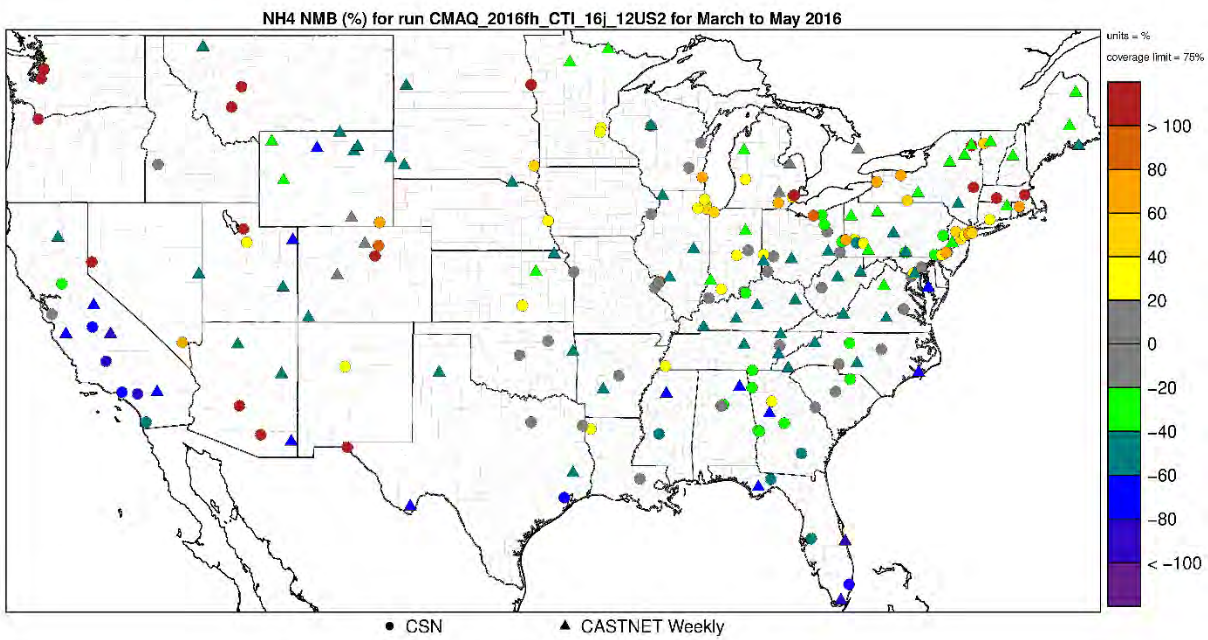

Figure 5-61 Normalized Mean Bias (%) of ammonium during spring 2016 at monitoring sites in the modeling domain

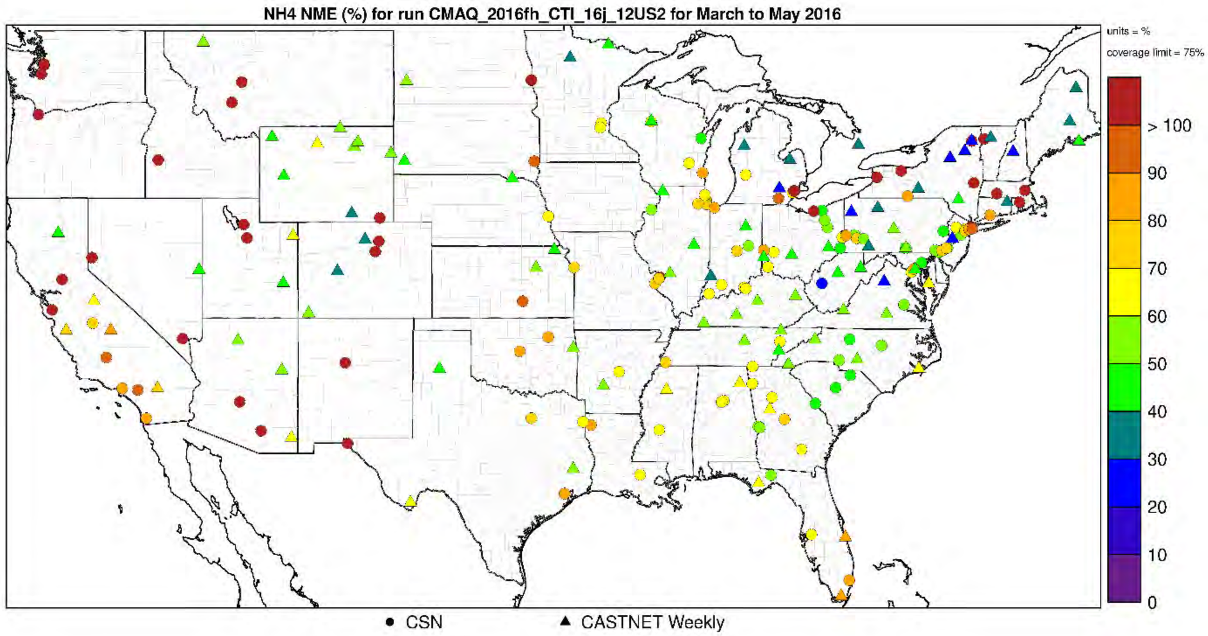

Figure 5-62 Normalized Mean Error (%) of ammonium during spring 2016 at monitoring sites in the modeling domain

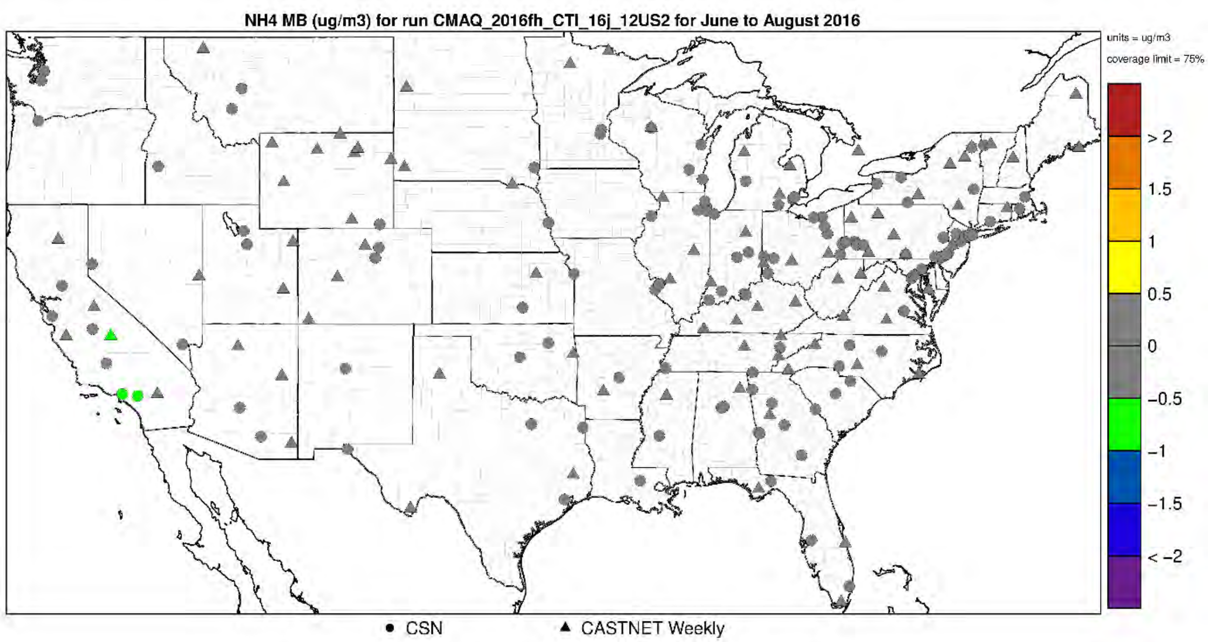

Figure 5-63 Mean Bias (ug/m3) of ammonium during summer 2016 at monitoring sites in the modeling domain

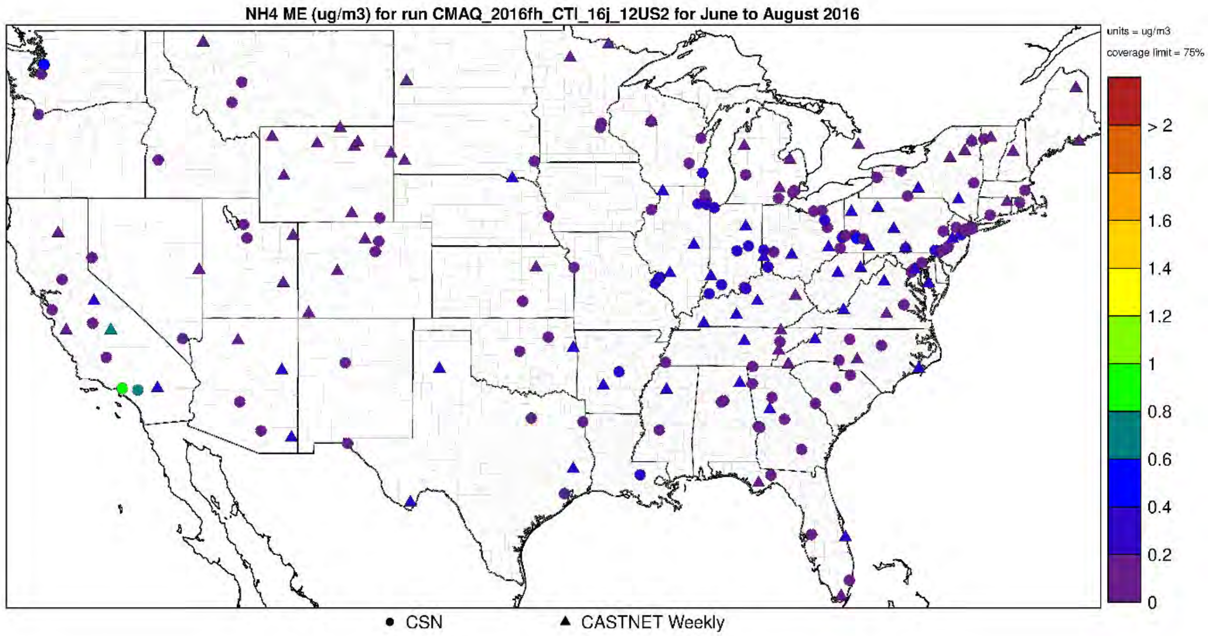

Figure 5-64 Mean Error (ug/m3) of ammonium during summer 2016 at monitoring sites in the modeling domain

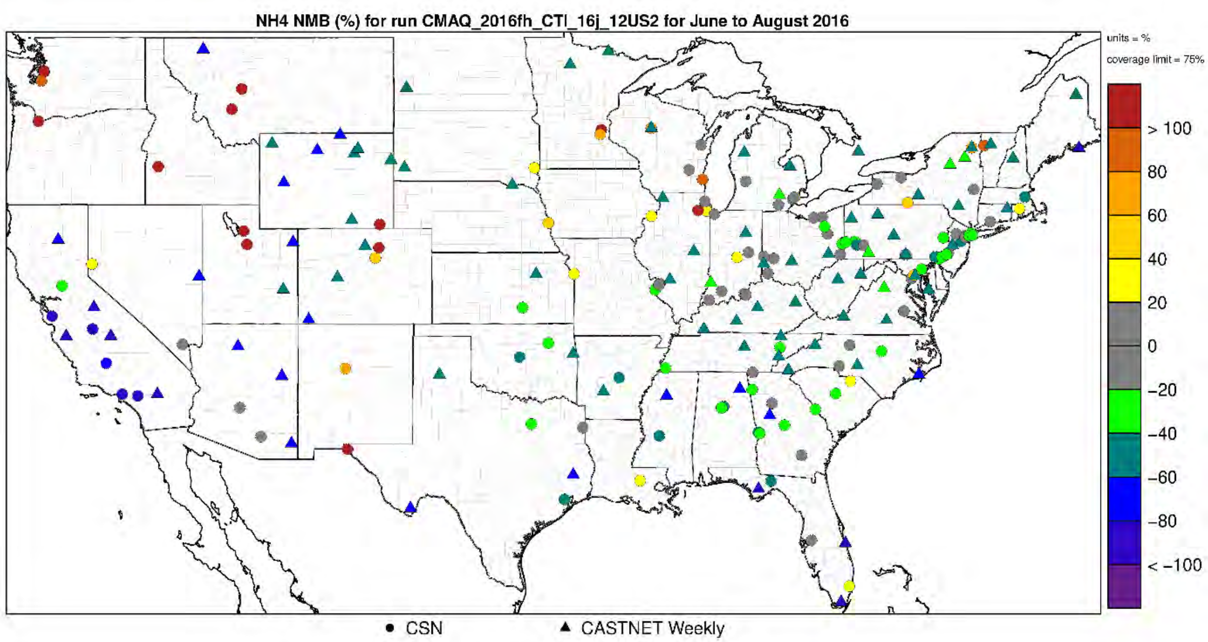

Figure 5-65 Normalized Mean Bias (%) of ammonium during summer 2016 at monitoring sites in the modeling domain

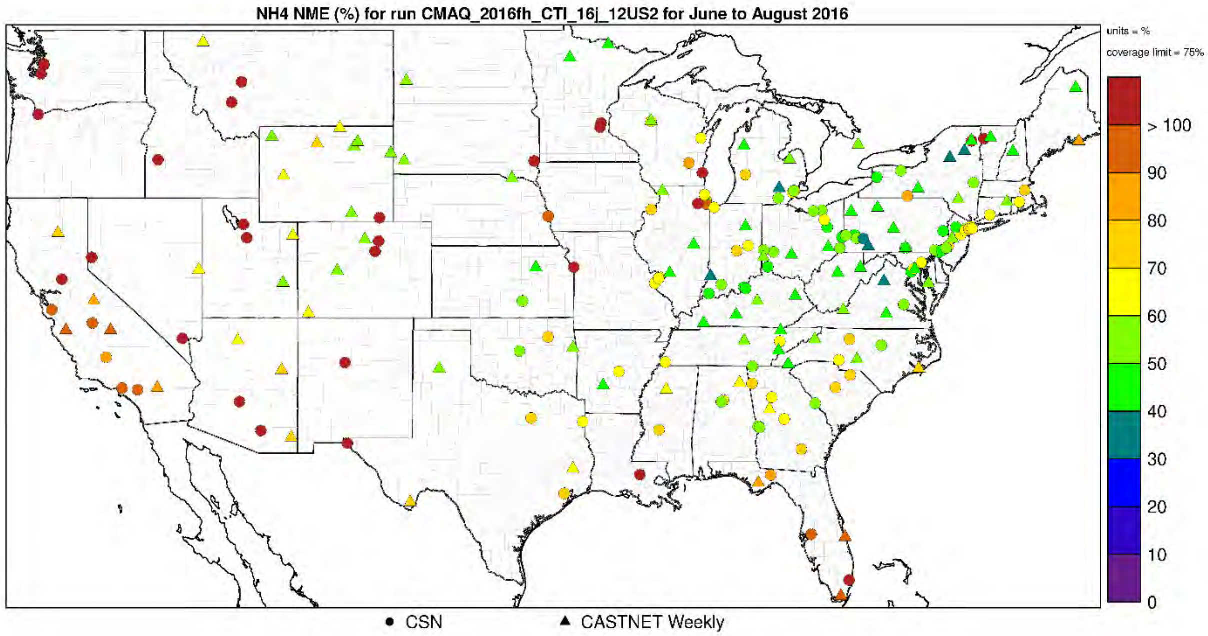

Figure 5-66 Normalized Mean Error (%) of ammonium during summer 2016 at monitoring sites in the modeling domain

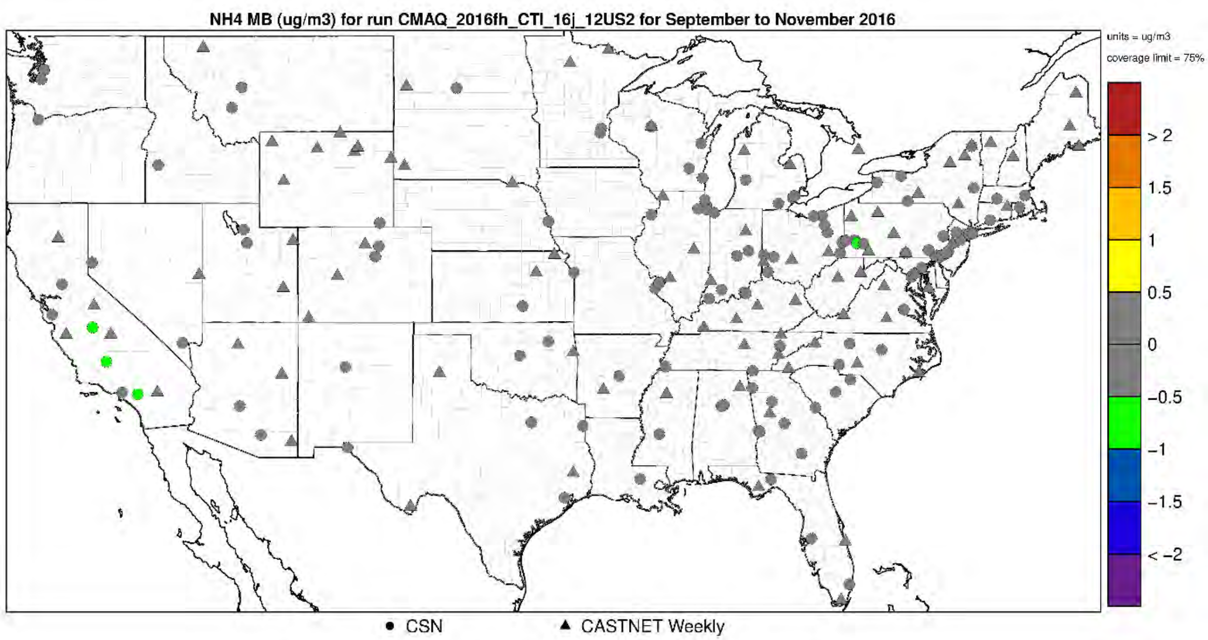

Figure 5-67 Mean Bias (ug/m^3) of ammonium during fall 2016 at monitoring sites in the modeling domain

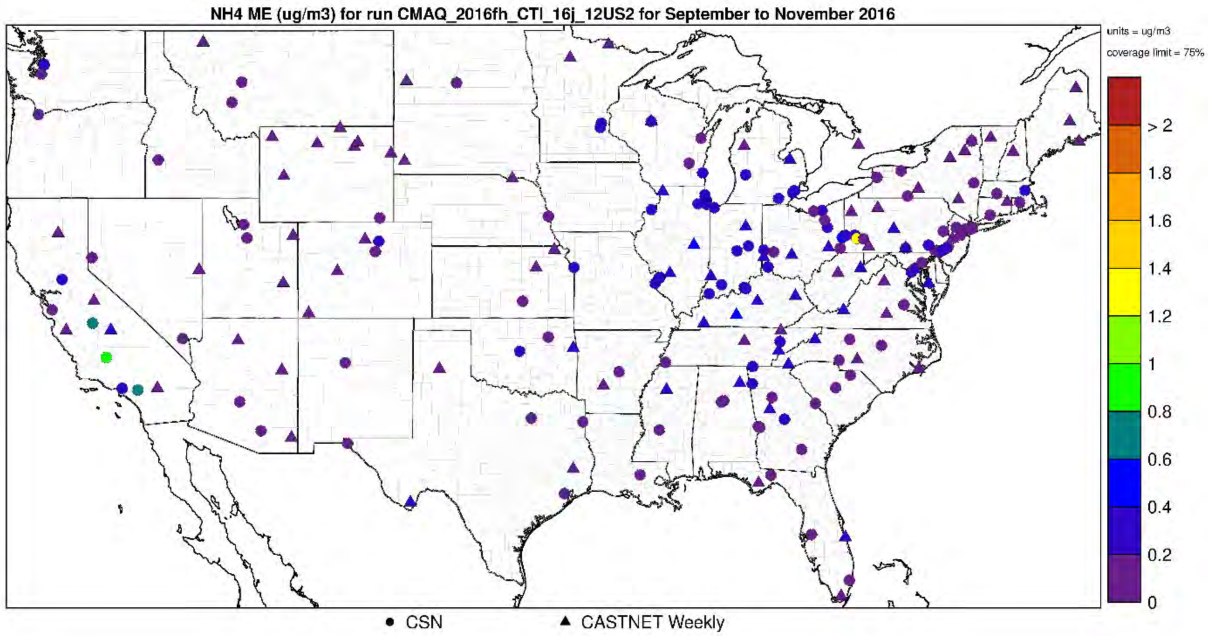

Figure 5-68 Mean Error (ug/m^3) of ammonium during fall 2016 at monitoring sites in the modeling domain

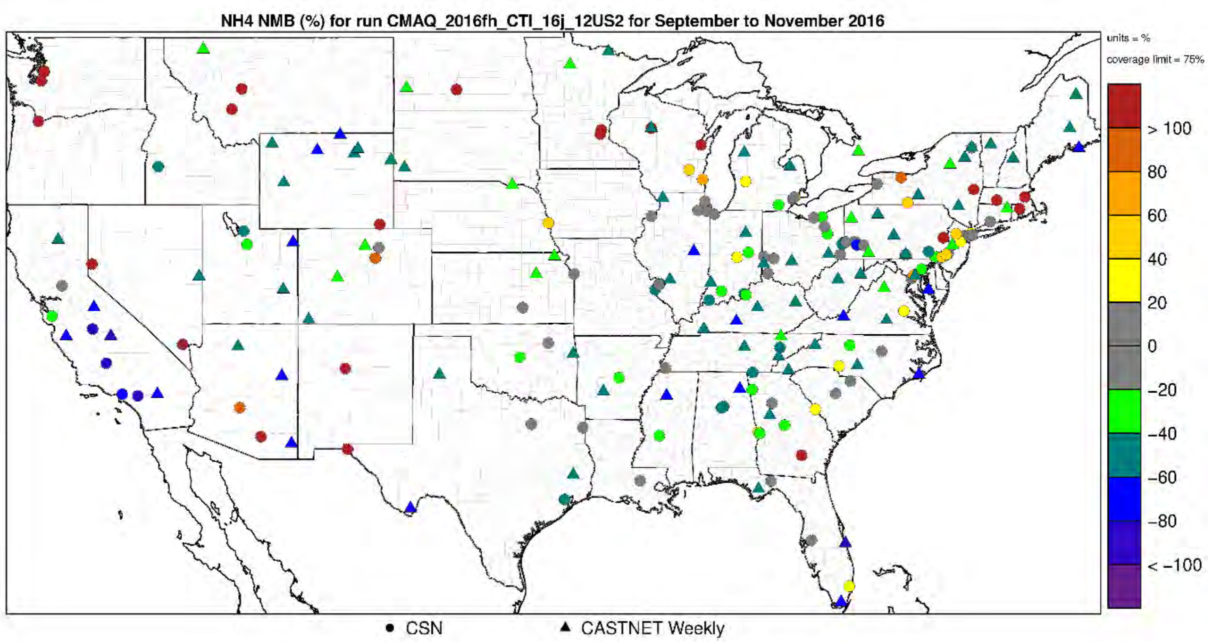

Figure 5-69 Normalized Mean Bias (%) of ammonium during fall 2016 at monitoring sites in the modeling domain

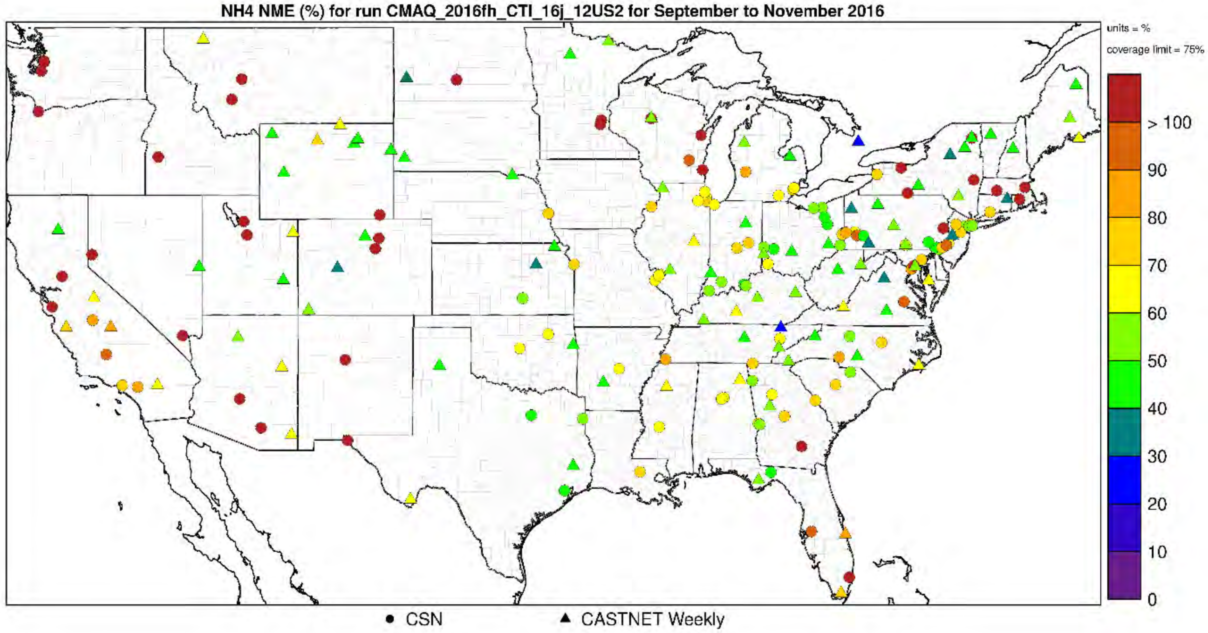

Figure 5-70 Normalized Mean Error (%) of ammonium during fall 2016 at monitoring sites in the modeling domain

5.4.4.4 Seasonal Elemental Carbon Performance

The model performance bias and error statistics for elemental carbon for each of the nine climate regions and each season are provided in Table 5-8. The statistics show clear over prediction at urban and rural sites in most climate regions. Spatial plots of the mean bias and error as well as normalized mean bias and error by season for individual monitors are shown in Figure 5-71 through Figure 5-86. In the Northwest, issues in the ambient data when compared to model predictions were found and thus removed from the performance analysis.

Table 5-8 Elemental Carbon Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2016 CMAQ Model Simulation

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	IMPROVE	Winter	429	0.1	0.1	48.9	72.7
		Spring	478	0.0	0.1	21.3	49.5
		Summer	479	0.0	0.1	3.7	41.6
		Fall	456	0.0	0.1	9.3	44.0
	CSN	Winter	710	0.2	0.4	29.1	62.4
		Spring	785	0.0	0.3	1.0	46.5

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Summer	766	-0.1	0.2	-13.0	42.3
		Fall	771	0.1	0.3	16.6	52.2
Ohio Valley	IMPROVE	Winter	217	0.1	0.2	46.5	82.5
		Spring	242	0.0	0.1	-7.6	54.2
		Summer	241	-0.1	0.1	-30.6	35.6
		Fall	232	-0.1	0.1	-25.8	36.8
	CSN	Winter	498	0.1	0.2	12.5	43.9
		Spring	540	-0.1	0.2	-19.1	39.2
		Summer	501	-0.1	0.2	-24.6	39.1
		Fall	505	-0.1	0.2	-12.7	35.1
Upper Midwest	IMPROVE	Winter	214	0.1	0.1	37.9	51.1
		Spring	239	0.0	0.1	-17.1	40.7
		Summer	236	0.0	0.1	-23.6	41.7
		Fall	214	0.1	0.1	37.9	51.1
	CSN	Winter	296	0.2	0.3	60.4	77.7
		Spring	316	0.0	0.2	0.2	48.8
		Summer	306	0.0	0.2	-6.1	45.9
		Fall	308	0.0	0.2	7.8	47.8
Southeast	IMPROVE	Winter	398	0.0	0.1	-0.7	54.3
		Spring	446	-0.1	0.2	-38.5	57.5
		Summer	442	-0.1	0.1	-23.3	48.4
		Fall	422	-0.1	0.1	-28.2	39.6
	CSN	Winter	395	0.0	0.3	-2.8	43.8
		Spring	449	-0.1	0.2	-18.6	43.1
		Summer	414	0.0	0.2	-5.6	51.3
		Fall	400	-0.1	0.3	-17.8	42.2
South	IMPROVE	Winter	240	0.0	0.1	-5.6	40.1
		Spring	272	0.0	0.1	-5.2	49.7
		Summer	242	0.0	0.0	-26.8	39.8

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Fall	262	-0.1	0.1	-31.9	40.4
	CSN	Winter	237	-0.1	0.2	-9.6	38.7
		Spring	266	-0.1	0.2	-16.3	37.4
		Summer	222	0.0	0.2	-5.0	49.8
		Fall	208	0.0	0.3	-2.6	44.2
Southwest	IMPROVE	Winter	890	-0.1	0.1	-28.6	58.7
		Spring	981	0.0	0.1	7.4	68.0
		Summer	962	0.0	0.1	-29.2	57.6
		Fall	945	0.0	0.1	-22.4	55.7
	CSN	Winter	215	0.1	0.4	9.1	43.3
		Spring	254	0.2	0.2	57.3	68.7
		Summer	236	0.1	0.2	26.8	54.3
		Fall	226	0.1	0.3	21.8	52.3
Northern Rockies	IMPROVE	Winter	557	0.0	0.0	12.8	70.3
		Spring	594	0.0	0.0	-24.7	63.0
		Summer	616	0.0	0.1	-20.7	62.1
		Fall	585	0.0	0.0	-32.0	52.8
	CSN	Winter	124	0.0	0.3	0.6	100.0
		Spring	145	0.0	0.1	-15.7	54.8
		Summer	161	-0.1	0.1	-24.8	46.8
		Fall	146	0.0	0.2	-19.5	65.9
Northwest	IMPROVE	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-
	CSN	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
West	IMPROVE	Winter	540	0.0	0.1	-18.2	61.5
		Spring	600	0.0	0.1	24.2	67.8
		Summer	601	0.0	0.1	-24.5	61.5
		Fall	565	0.0	0.1	-15.3	55.1
	CSN	Winter	266	-0.1	0.4	-7.4	40.0
		Spring	293	0.2	0.2	42.9	56.2
		Summer	267	0.1	0.2	29.0	46.3
		Fall	255	0.2	0.3	22.7	46.6

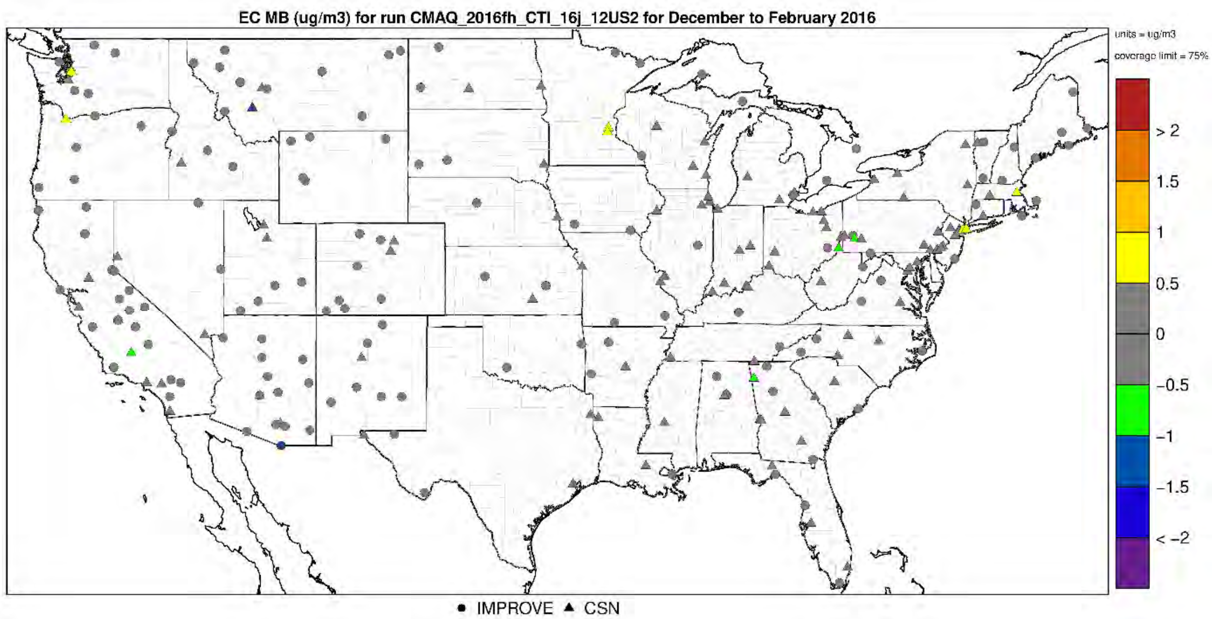

Figure 5-71 Mean Bias (ug/m3) of elemental carbon during winter 2016 at monitoring sites in the modeling domain

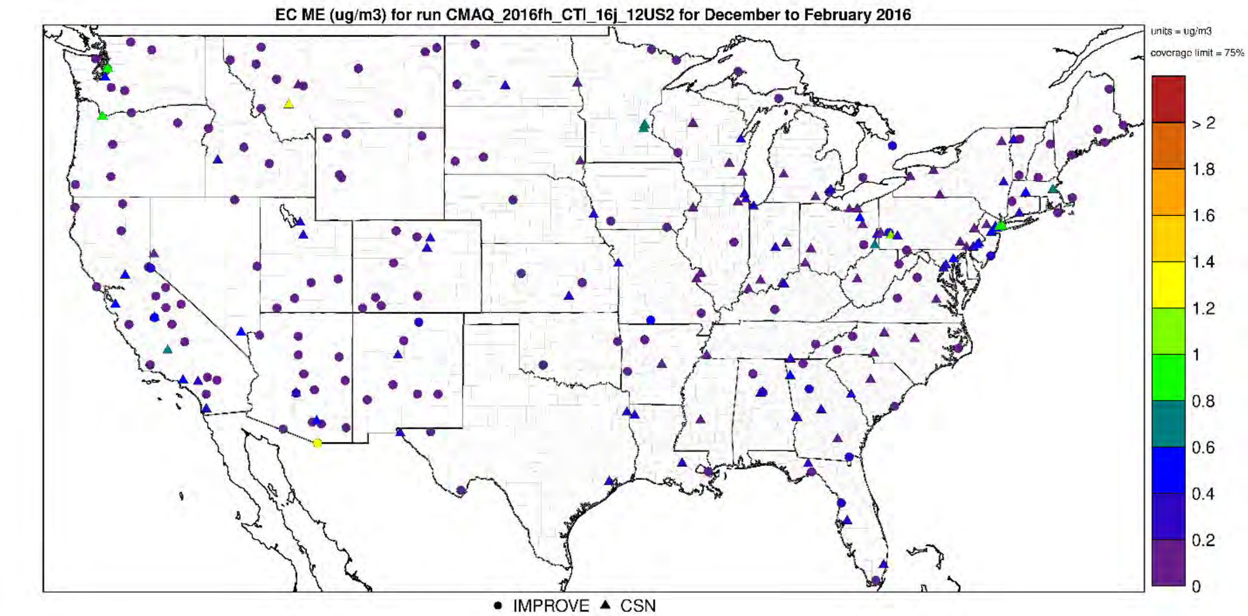

Figure 5-72 Mean Error (ug/m3) of elemental carbon during winter 2016 at monitoring sites in the modeling domain

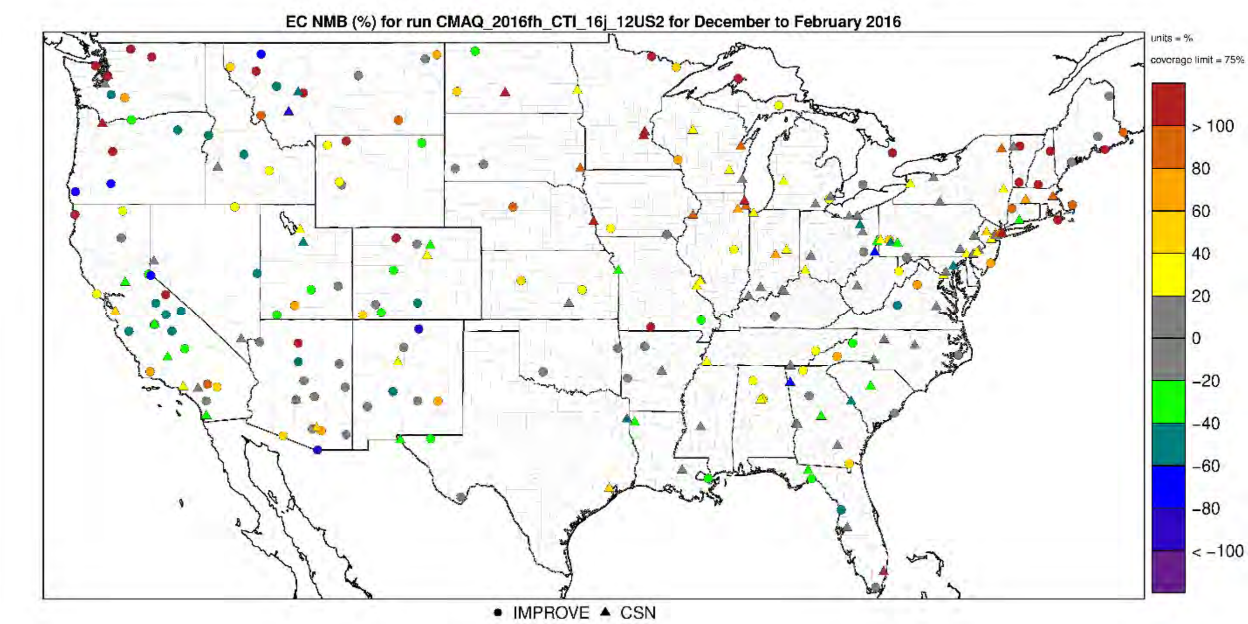

Figure 5-73 Normalized Mean Bias (%) of elemental carbon during winter 2016 at monitoring sites in the modeling domain

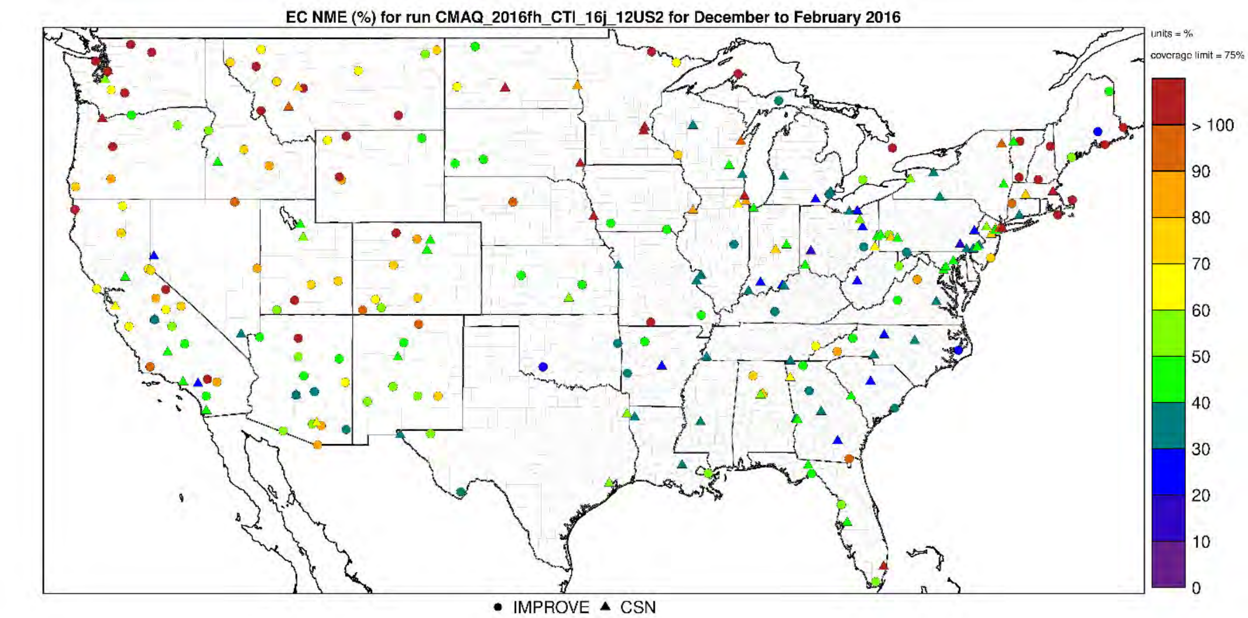

Figure 5-74 Normalized Mean Error (%) of elemental carbon during winter 2016 at monitoring sites in the modeling domain

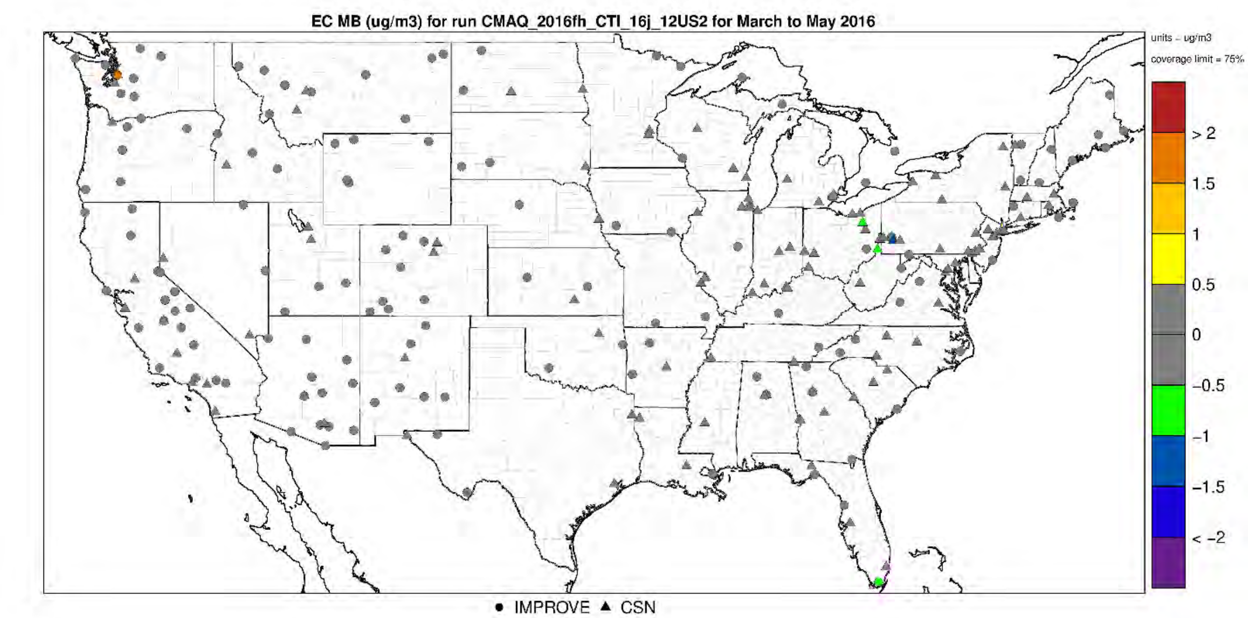

Figure 5-75 Mean Bias (ug/m^3) of elemental carbon during spring 2016 at monitoring sites in the modeling domain

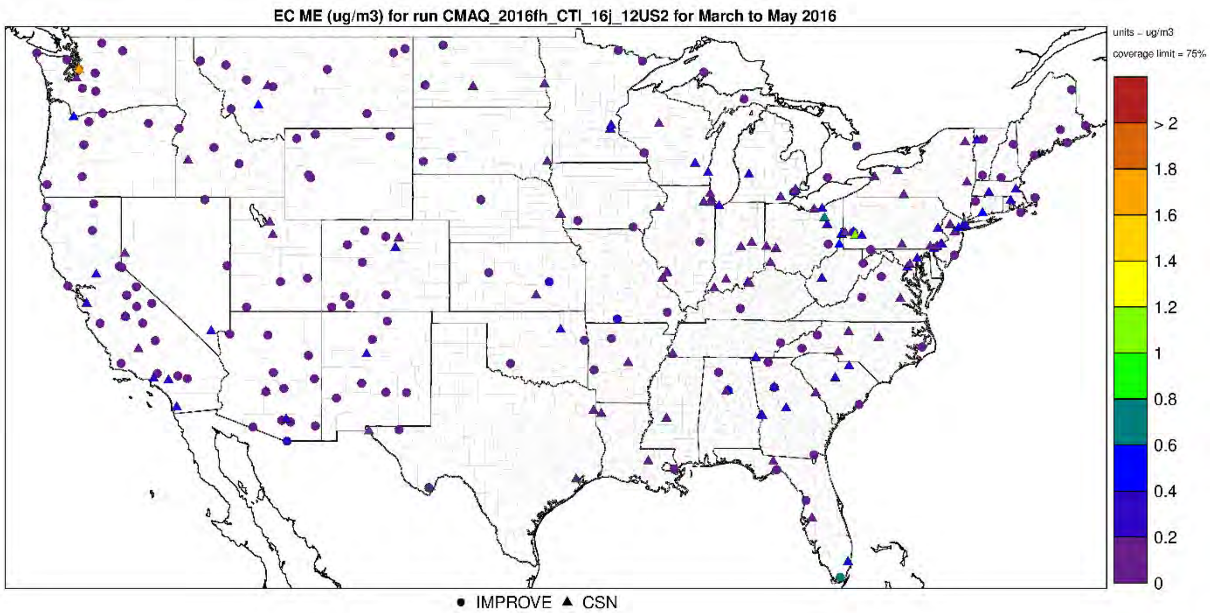

Figure 5-76 Mean Error (ug/m^3) of elemental carbon during spring 2016 at monitoring sites in the modeling domain

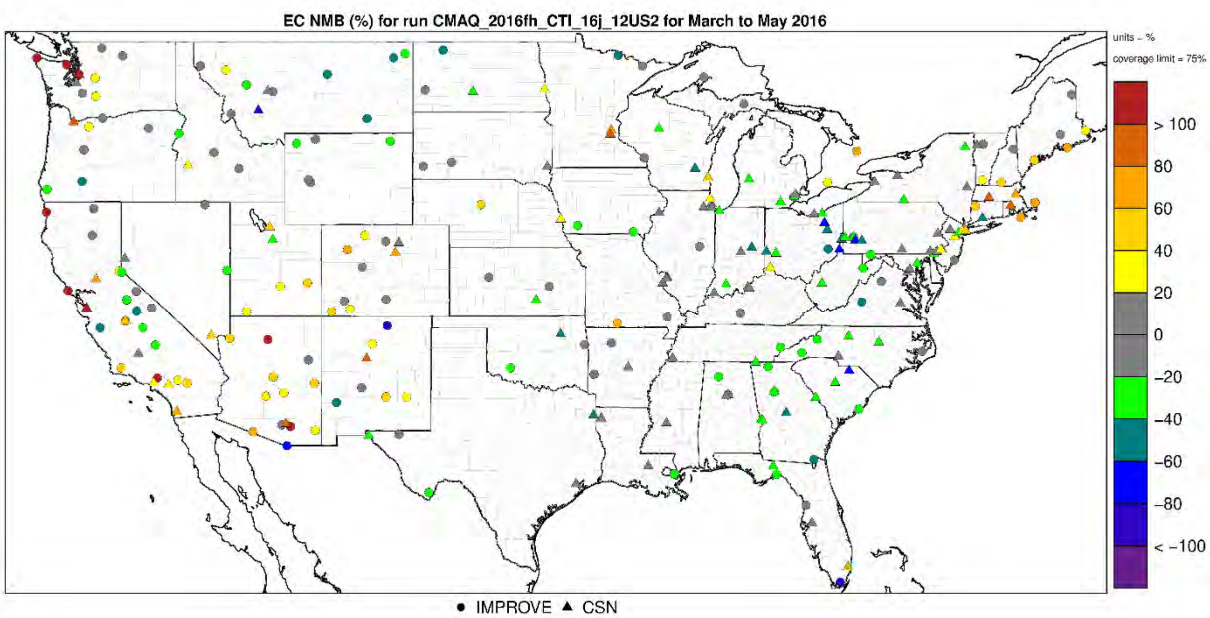

Figure 5-77 Normalized Mean Bias (%) of elemental carbon during spring 2016 at monitoring sites in the modeling domain

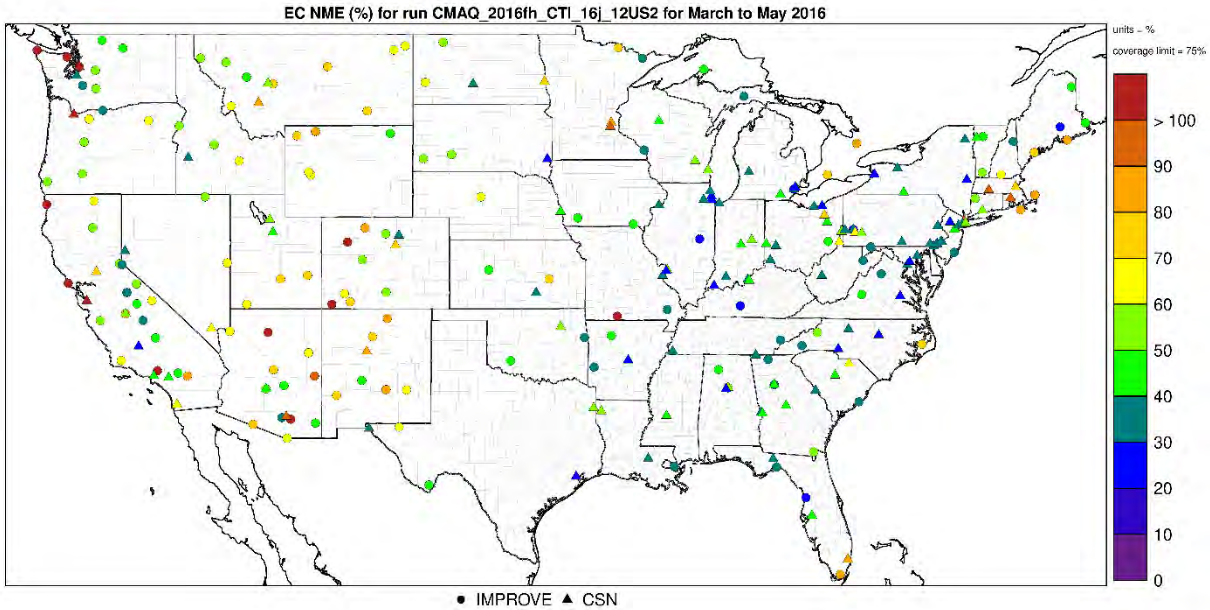

Figure 5-78 Normalized Mean Error (%) of elemental carbon during spring 2016 at monitoring sites in the modeling domain

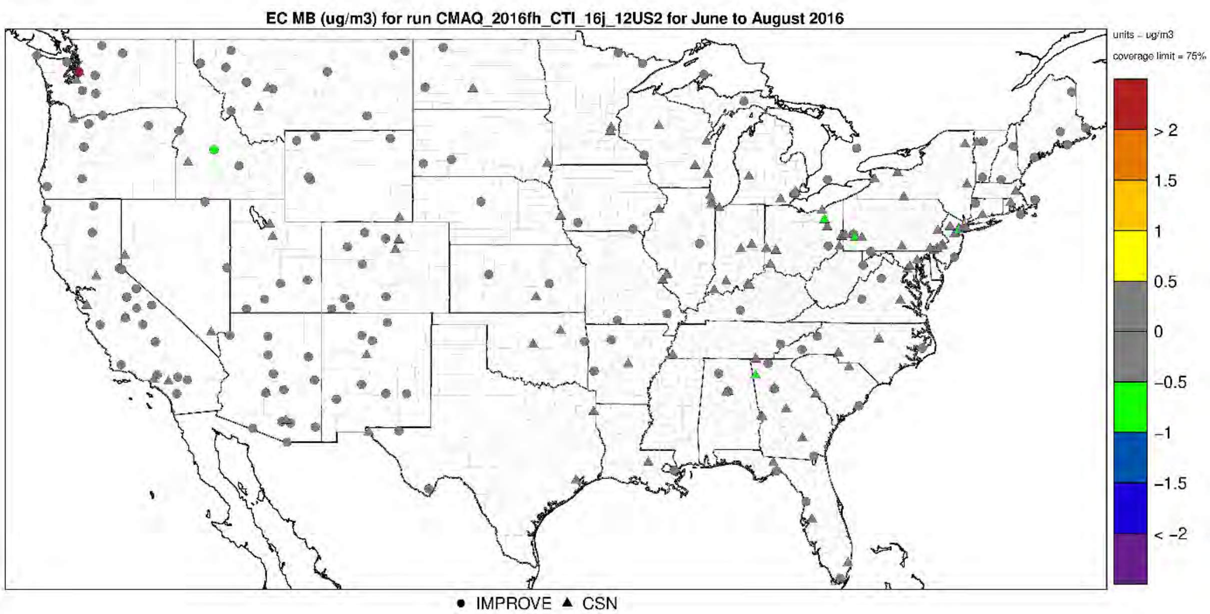

Figure 5-79 Mean Bias (ug/m3) of elemental carbon during summer 2016 at monitoring sites in the modeling domain

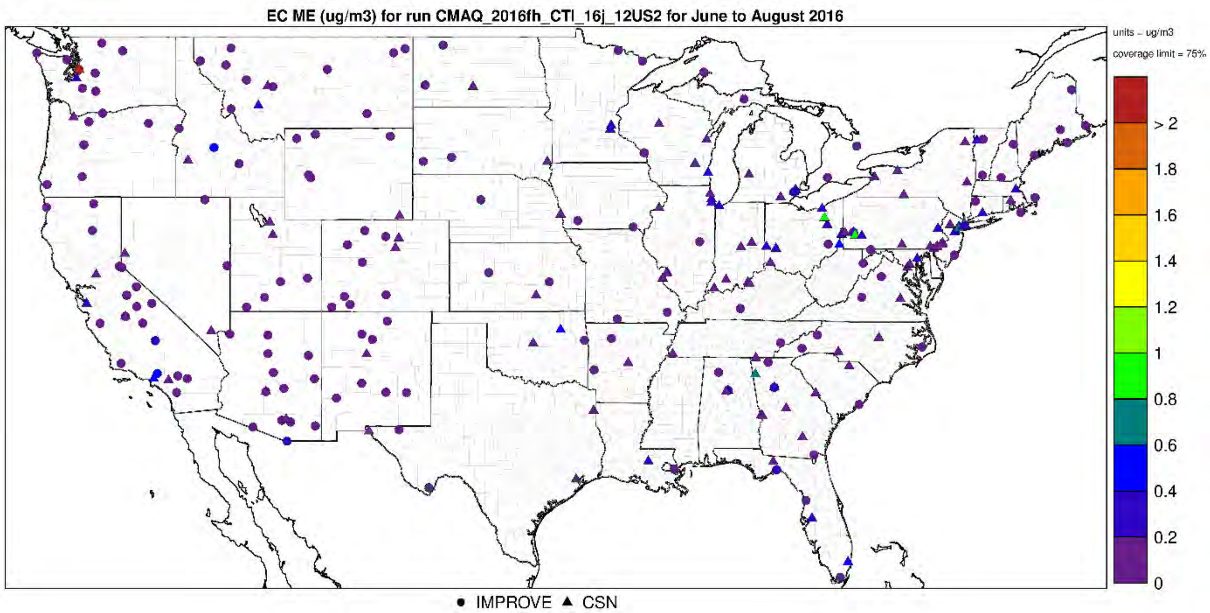

Figure 5-80 Mean Error (ug/m3) of elemental carbon during summer 2016 at monitoring sites in the modeling domain

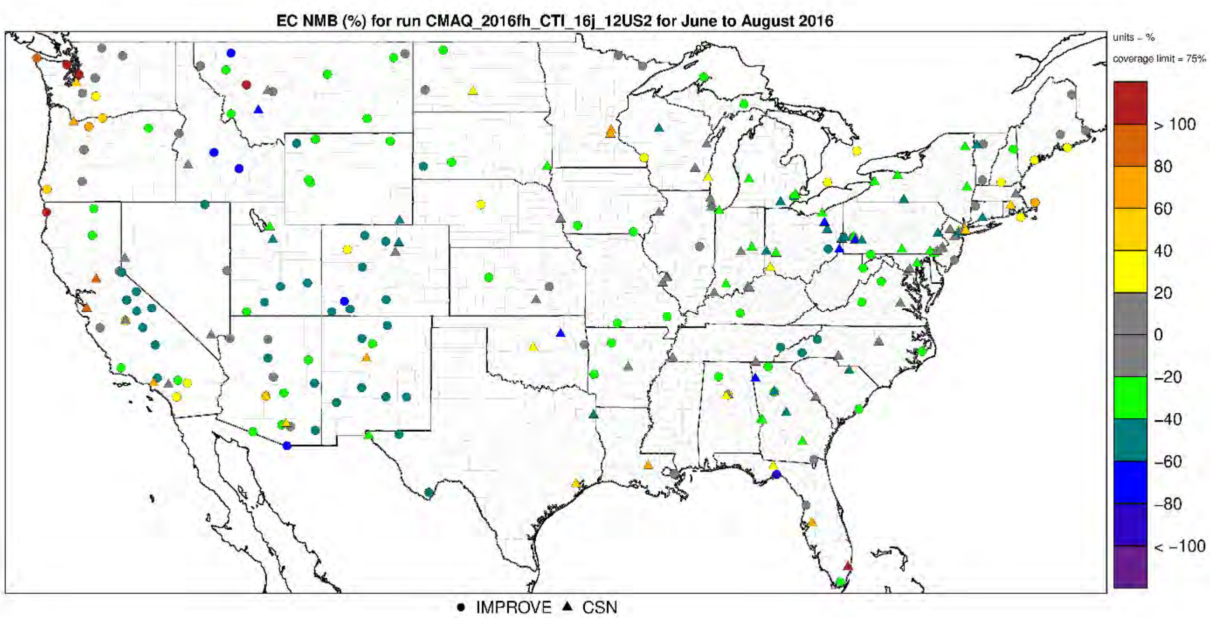

Figure 5-81 Normalized Mean Bias (%) of elemental carbon during summer 2016 at monitoring sites in the modeling domain

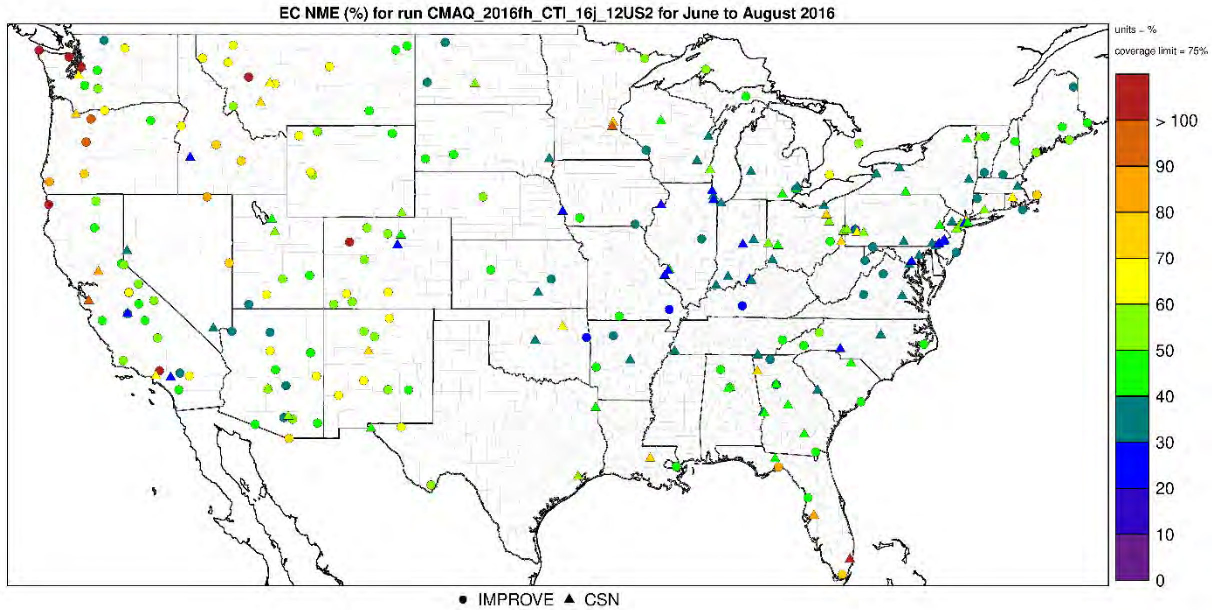

Figure 5-82 Normalized Mean Error (%) of elemental carbon during summer 2016 at monitoring sites in the modeling domain

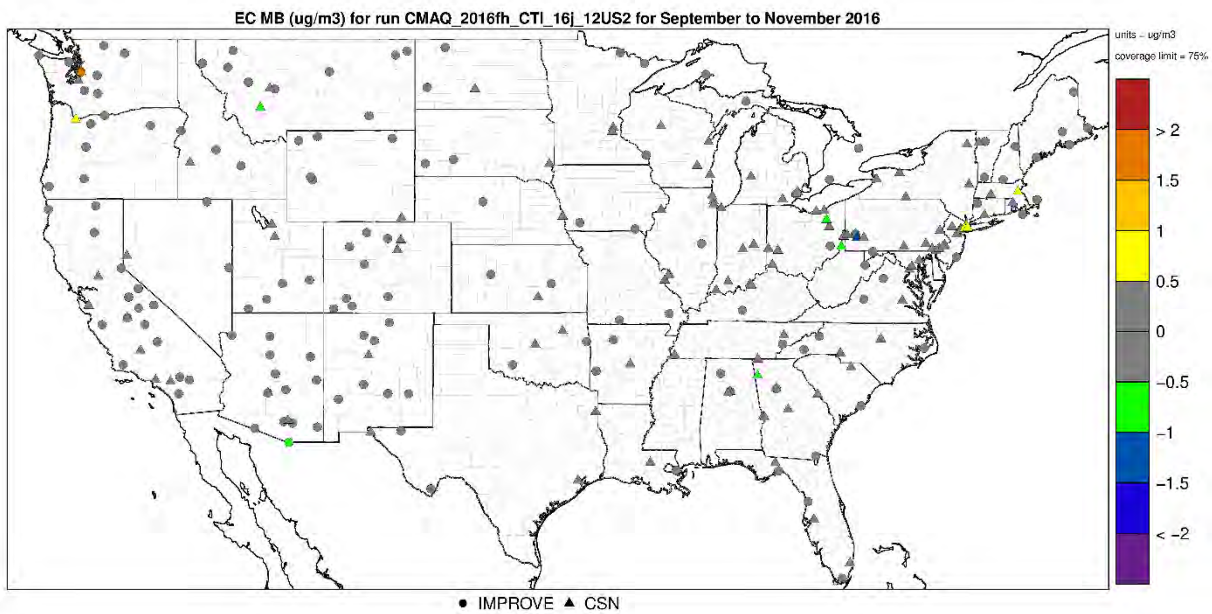

Figure 5-83 Mean Bias (ug/m^3) of elemental carbon during fall 2016 at monitoring sites in the modeling domain

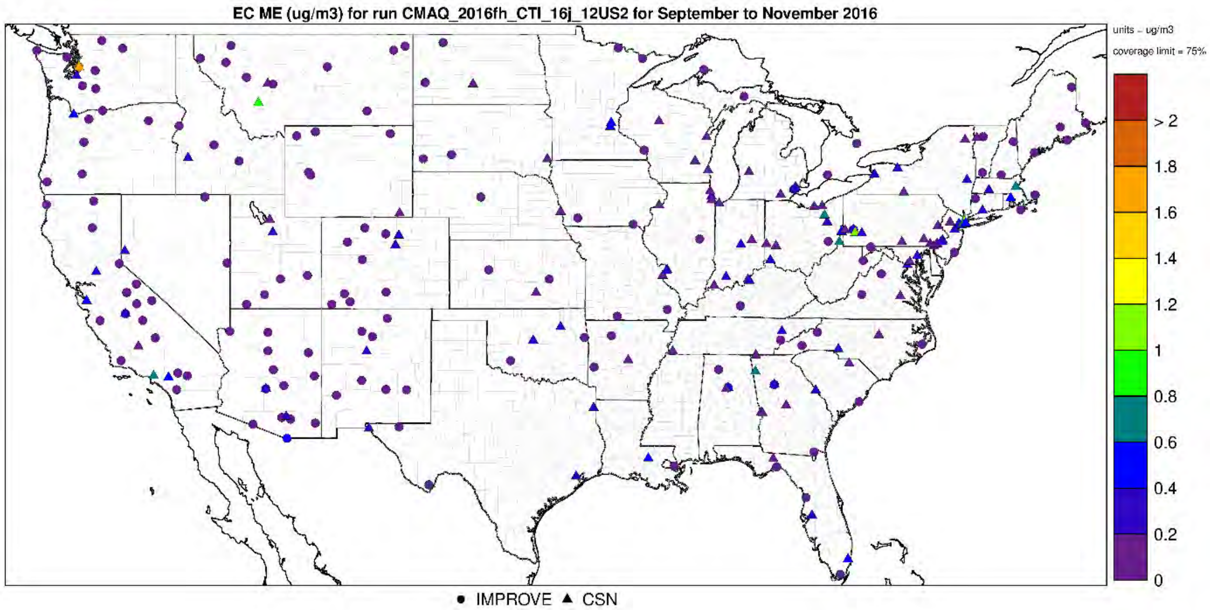

Figure 5-84 Mean Error (ug/m^3) of elemental carbon during fall 2016 at monitoring sites in the modeling domain

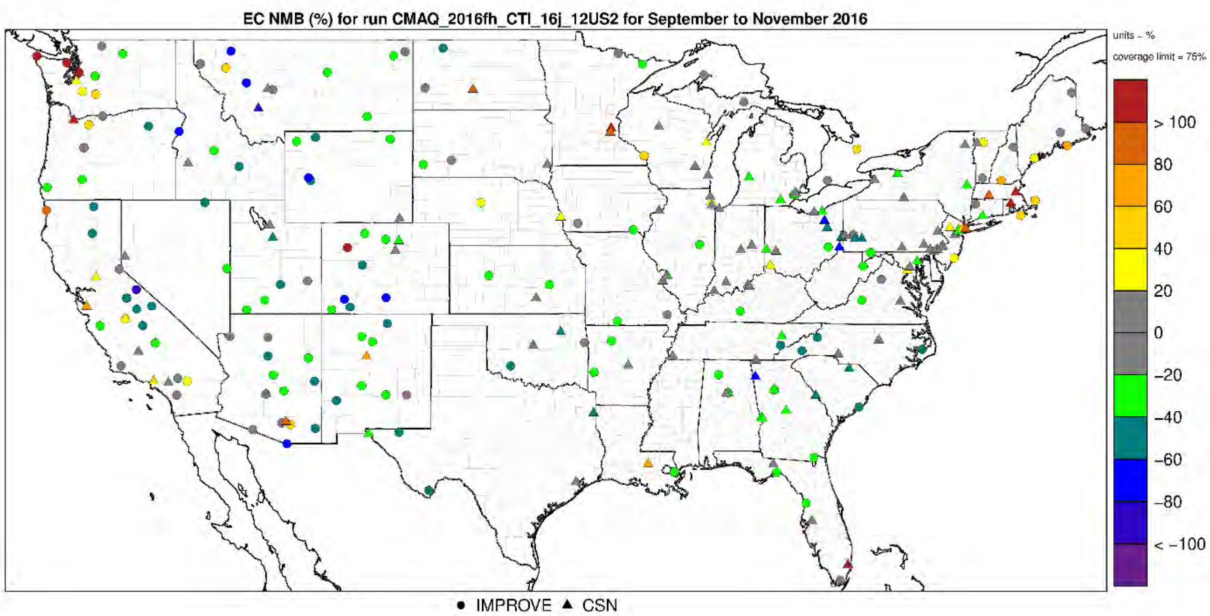

Figure 5-85 Normalized Mean Bias (%) of elemental carbon during fall 2016 at monitoring sites in the modeling domain

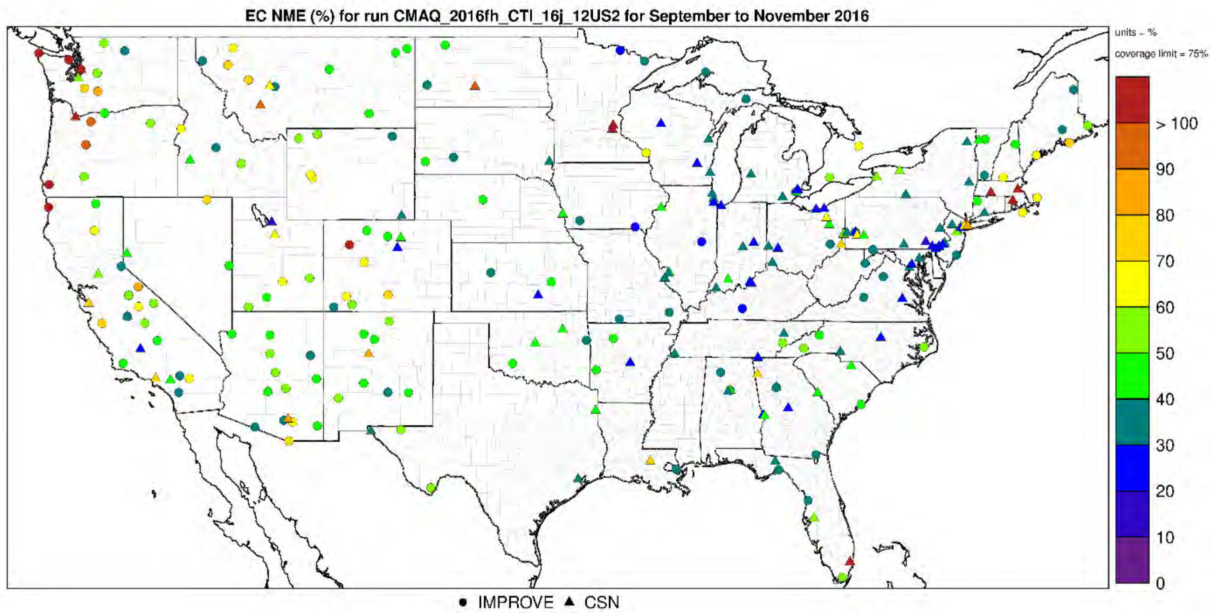

Figure 5-86 Normalized Mean Error (%) of elemental carbon during fall 2016 at monitoring sites in the modeling domain

5.4.4.5 Seasonal Organic Carbon Performance

The model performance bias and error statistics for organic carbon for each climate region and season are provided in Table 5-9. The statistics in this table indicate a tendency for the modeling platform to over predict observed organic carbon concentrations during most seasons and climate regions except in the Northern Rockies and the Western U.S. Spatial plots of the mean bias and error as well as normalized mean bias and error by season for individual monitors are shown in Figure 5-87 through Figure 5-102.

Table 5-9 Organic Carbon Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2016 CMAQ Model Simulation

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	IMPROVE	Winter	427	1.1	1.2	>100	>100
		Spring	477	0.6	0.6	74.5	83.7
		Summer	482	0.4	0.6	36.9	51.6
		Fall	459	0.7	0.8	76.8	90.8
	CSN	Winter	710	2.2	2.3	120.0	128.0

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Spring	785	1.0	1.2	63.7	73.8
		Summer	766	0.5	0.8	24.8	40.4
		Fall	771	1.3	1.5	68.5	79.1
Ohio Valley	IMPROVE	Winter	217	2.0	2.2	>100	>100
		Spring	242	0.9	1.1	80.9	>100
		Summer	242	0.6	0.8	42.3	57.5
		Fall	232	0.7	1.2	38.3	66.0
	CSN	Winter	498	1.0	1.2	63.3	75.8
		Spring	540	0.5	0.8	30.6	50.8
		Summer	500	0.5	0.8	28.2	45.1
		Fall	502	0.6	1.1	23.8	44.9
Upper Midwest	IMPROVE	Winter	218	0.8	0.8	>100	>100
		Spring	238	0.3	0.7	36.7	74.9
		Summer	237	0.2	0.5	15.3	43.5
		Fall	238	0.4	0.5	44.1	58.1
	CSN	Winter	296	1.7	1.7	>100	>100
		Spring	316	0.8	1.1	50.2	72.3
		Summer	305	0.6	0.8	33.6	46.9
		Fall	308	0.9	1.0	55.3	64.0
Southeast	IMPROVE	Winter	398	0.8	1.1	68.2	95.1
		Spring	447	-4.2	5.7	-66.6	91.3
		Summer	455	0.6	1.1	37.6	72.2
		Fall	423	0.6	1.3	31.0	68.1
	CSN	Winter	395	1.1	1.3	53.8	64.3
		Spring	449	1.2	1.4	56.1	67.9
		Summer	414	1.6	1.7	82.1	85.5
		Fall	400	1.3	2.1	44.4	72.5
South	IMPROVE	Winter	239	0.5	0.7	60.5	76.7
		Spring	272	0.3	0.7	24.7	65.4

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Summer	250	0.4	0.7	34.0	59.1
		Fall	264	0.4	0.7	35.9	58.9
	CSN	Winter	237	0.6	1.1	26.6	50.4
		Spring	266	0.5	0.9	33.9	55.6
		Summer	222	1.0	1.3	61.0	77.1
		Fall	207	1.2	1.5	51.1	62.4
Southwest	IMPROVE	Winter	881	0.0	0.4	1.1	66.7
		Spring	981	0.2	0.3	38.2	69.0
		Summer	978	0.2	0.5	17.2	55.6
		Fall	964	0.2	0.5	34.8	72.9
	CSN	Winter	215	0.9	1.7	36.3	67.1
		Spring	254	0.7	0.8	63.1	77.9
		Summer	236	0.4	0.7	25.7	48.5
		Fall	226	0.6	1.0	36.2	62.4
Northern Rockies	IMPROVE	Winter	549	0.1	0.2	40.9	79.7
		Spring	590	-0.1	0.4	-13.2	58.6
		Summer	631	-0.1	0.6	-5.9	49.6
		Fall	600	0.0	0.4	-8.0	56.9
	CSN	Winter	124	0.3	1.3	29.5	>100
		Spring	145	0.0	0.5	-1.0	60.3
		Summer	161	-0.4	0.6	-29.3	41.9
		Fall	146	-0.1	0.6	-9.0	56.4
Northwest	IMPROVE	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-
		Fall	-	-	-	-	-
	CSN	Winter	-	-	-	-	-
		Spring	-	-	-	-	-
		Summer	-	-	-	-	-

Climate Region	Monitor Network	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
		Fall	-	-	-	-	-
West	IMPROVE	Winter	552	-0.1	0.3	-17.2	52.2
		Spring	599	-0.1	0.3	-8.2	44.7
		Summer	608	-0.2	0.8	-10.9	48.8
		Fall	574	0.0	0.5	0.1	49.9
	CSN	Winter	265	-0.3	1.3	-7.4	35.8
		Spring	293	0.3	0.6	20.3	38.6
		Summer	266	-0.1	0.9	-2.4	34.1
		Fall	255	0.4	1.1	13.3	40.0

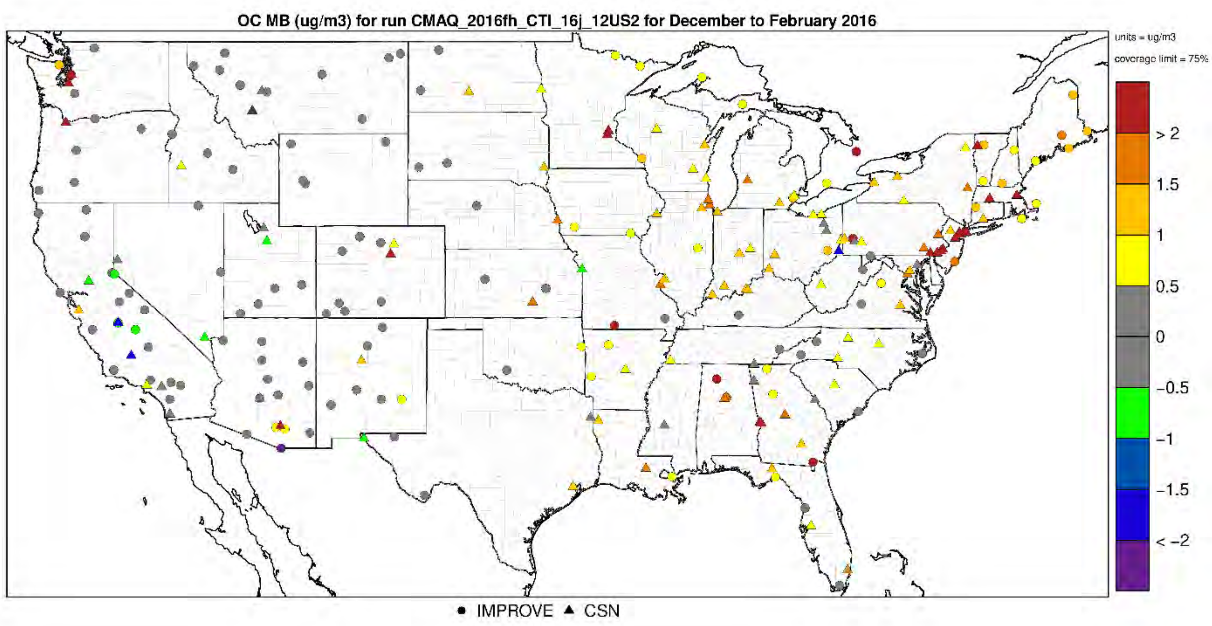

Figure 5-87 Mean Bias (ug/m3) of organic carbon during winter 2016 at monitoring sites in the modeling domain

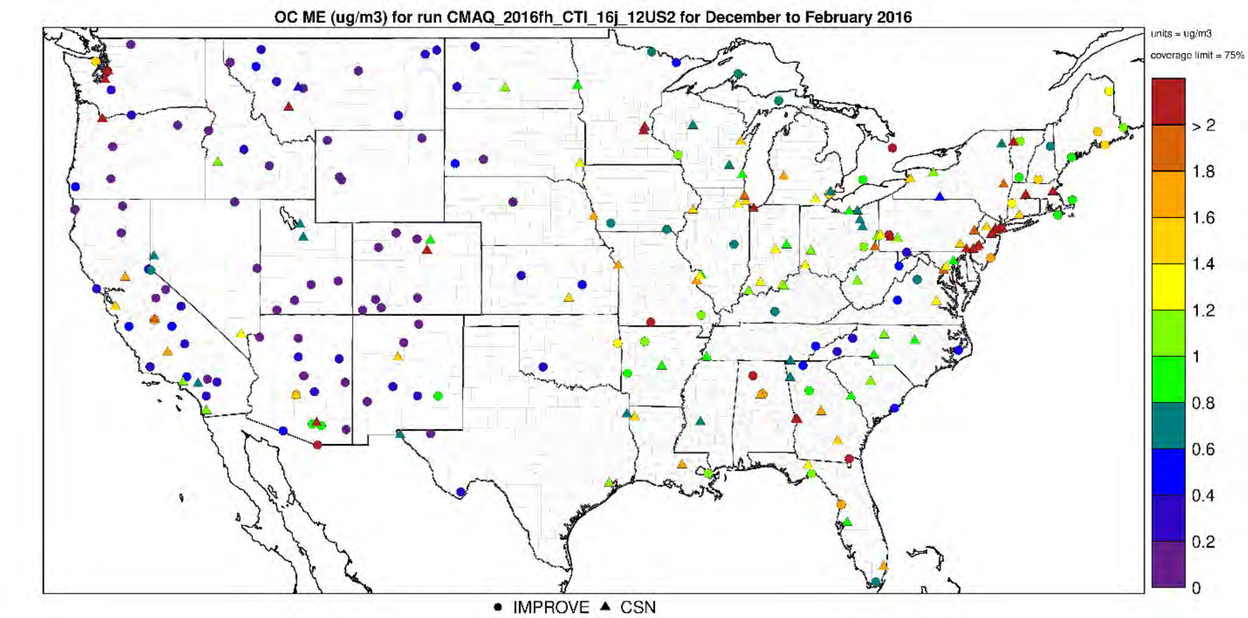

Figure 5-88 Mean Error (ug/m3) of organic carbon during winter 2016 at monitoring sites in the modeling domain

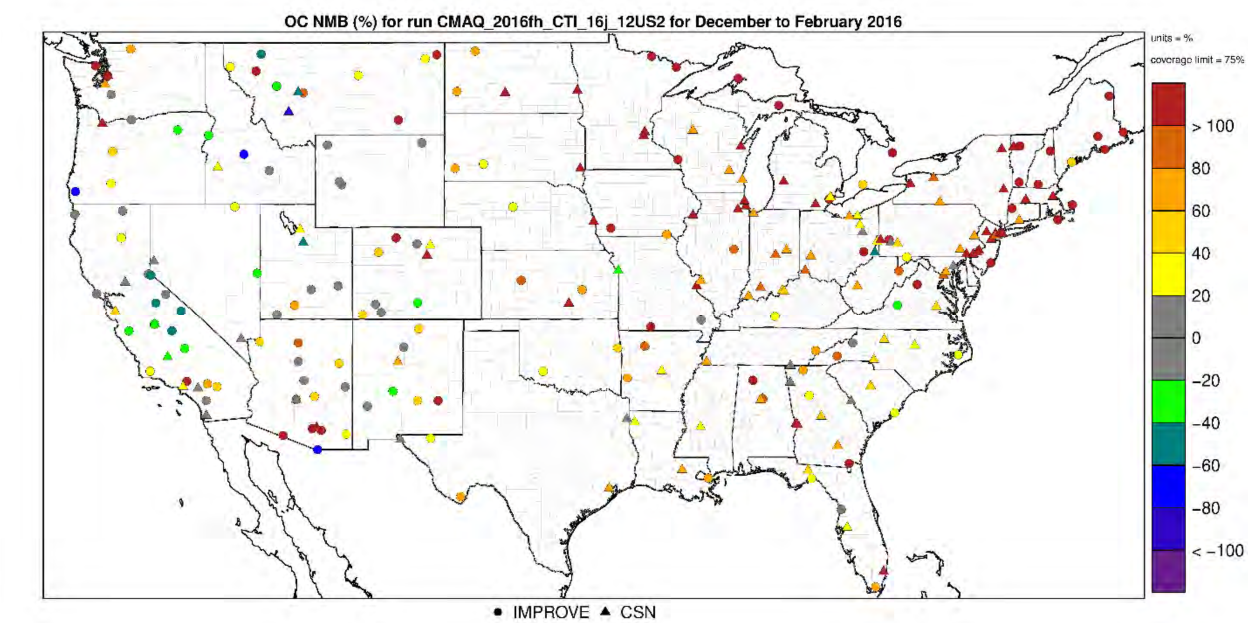

Figure 5-89 Normalized Mean Bias (%) of organic carbon during winter 2016 at monitoring sites in the modeling domain

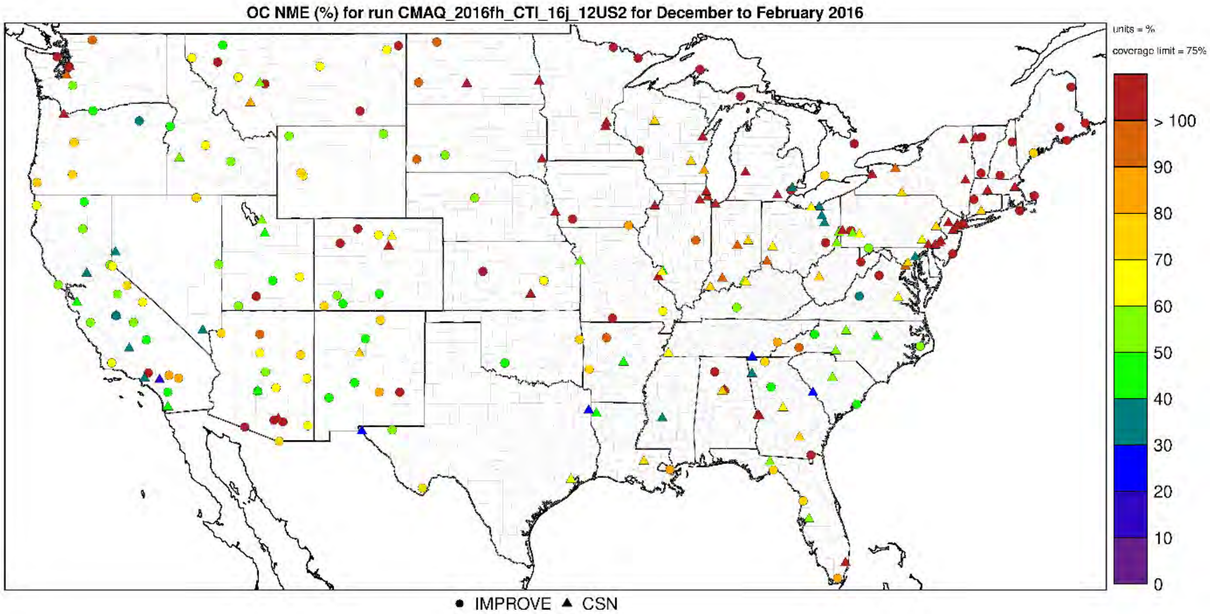

Figure 5-90 Normalized Mean Error (%) of organic carbon during winter 2016 at monitoring sites in the modeling domain

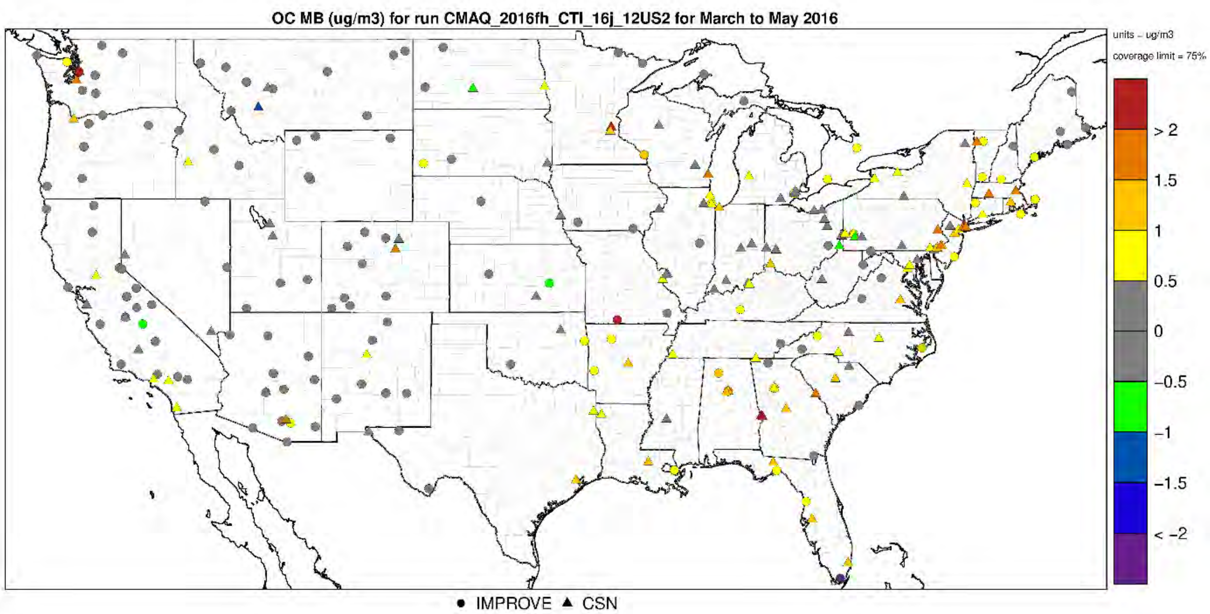

Figure 5-91 Mean Bias (ug/m^3) of organic carbon during spring 2016 at monitoring sites in the modeling domain

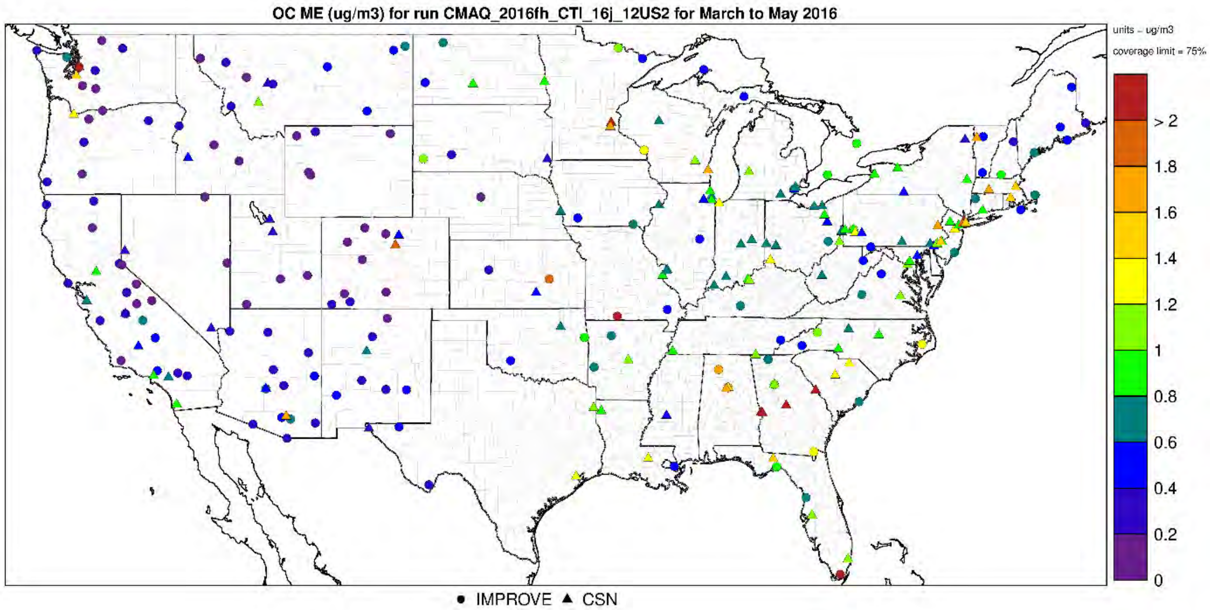

Figure 5-92 Mean Error (ug/m^3) of organic carbon during spring 2016 at monitoring sites in the modeling domain

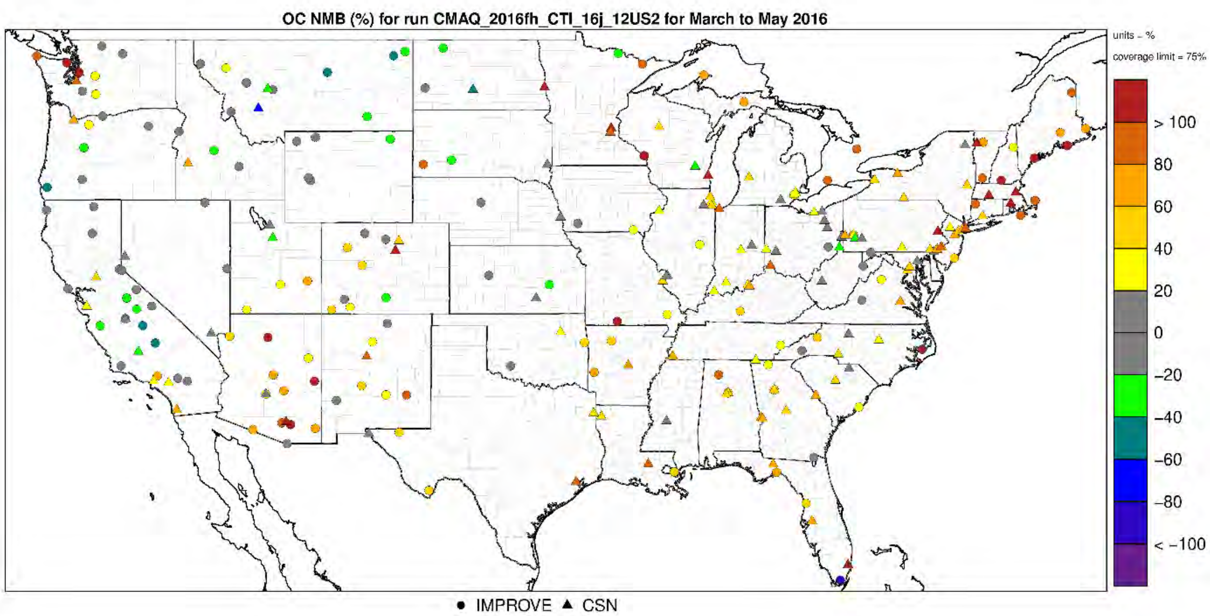

Figure 5-93 Normalized Mean Bias (%) of organic carbon during spring 2016 at monitoring sites in the modeling domain

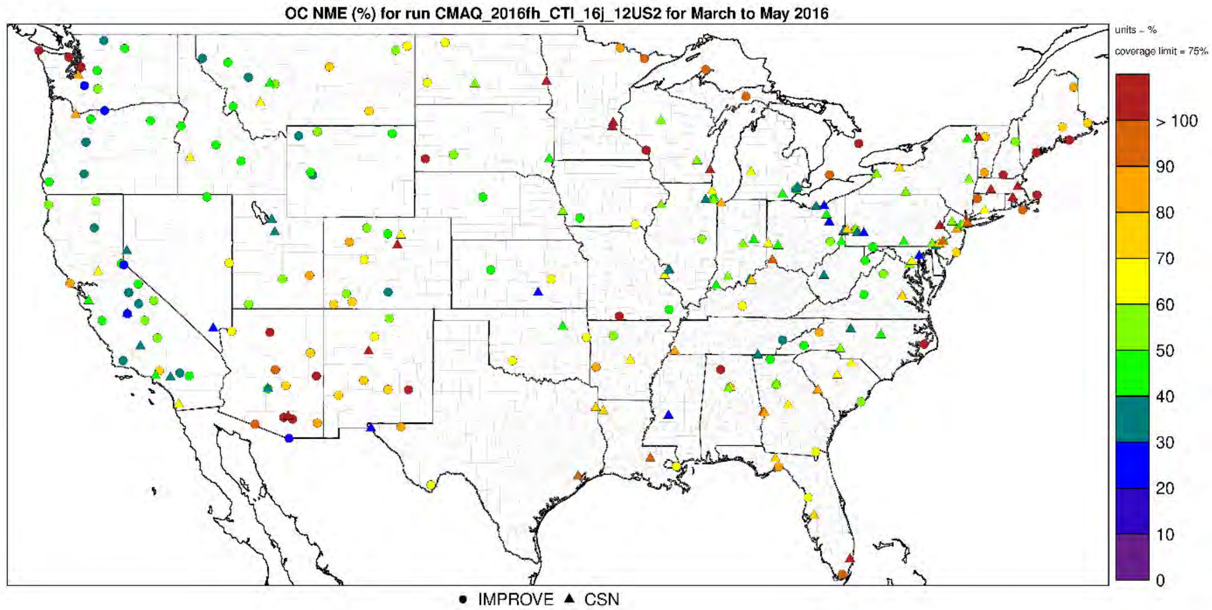

Figure 5-94 Normalized Mean Error (%) of organic carbon during spring 2016 at monitoring sites in the modeling domain

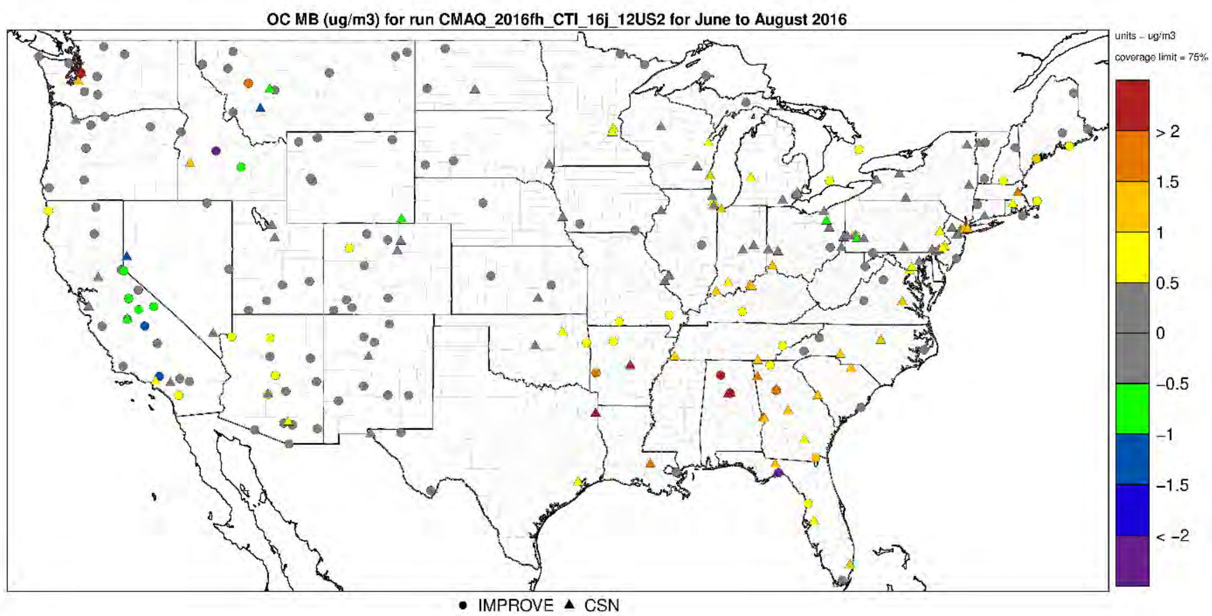

Figure 5-95 Mean Bias (ug/m3) of organic carbon during summer 2016 at monitoring sites in the modeling domain

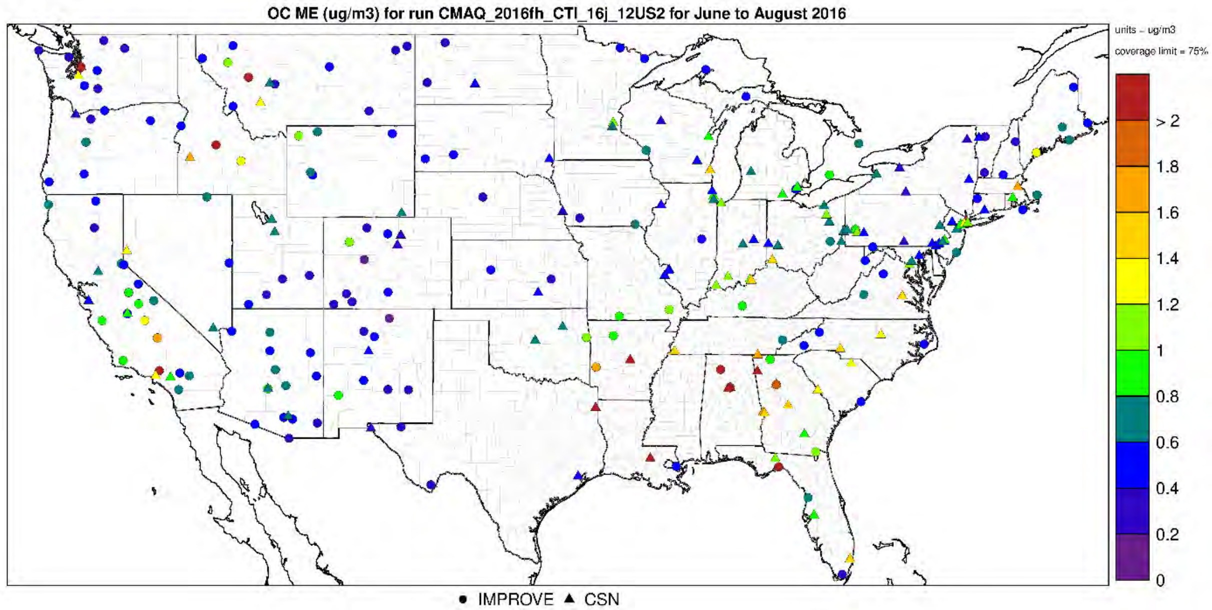

Figure 5-96 Mean Error (ug/m3) of organic carbon during summer 2016 at monitoring sites in the modeling domain

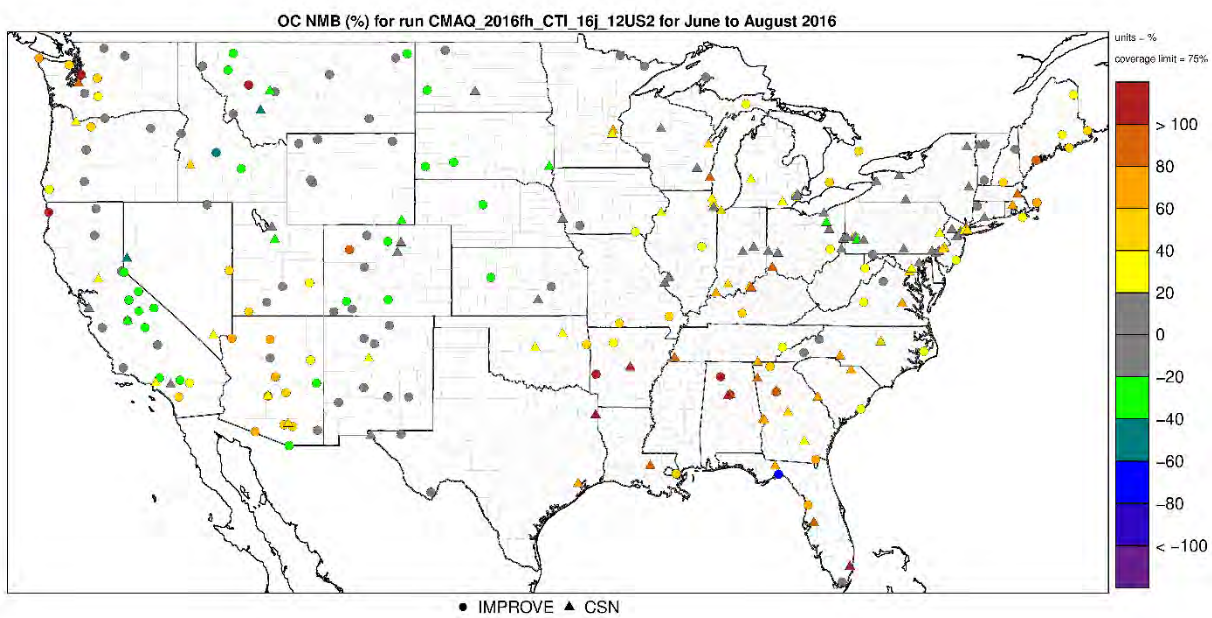

Figure 5-97 Normalized Mean Bias (%) of organic carbon during summer 2016 at monitoring sites in the modeling domain

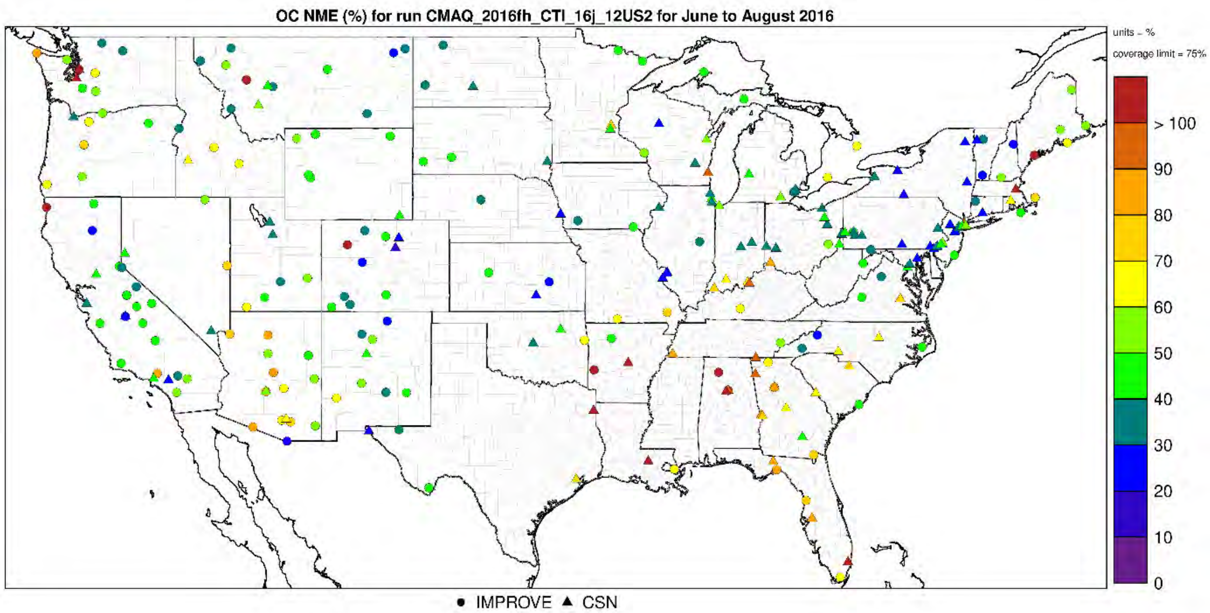

Figure 5-98 Normalized Mean Error (%) of organic carbon during summer 2016 at monitoring sites in the modeling domain

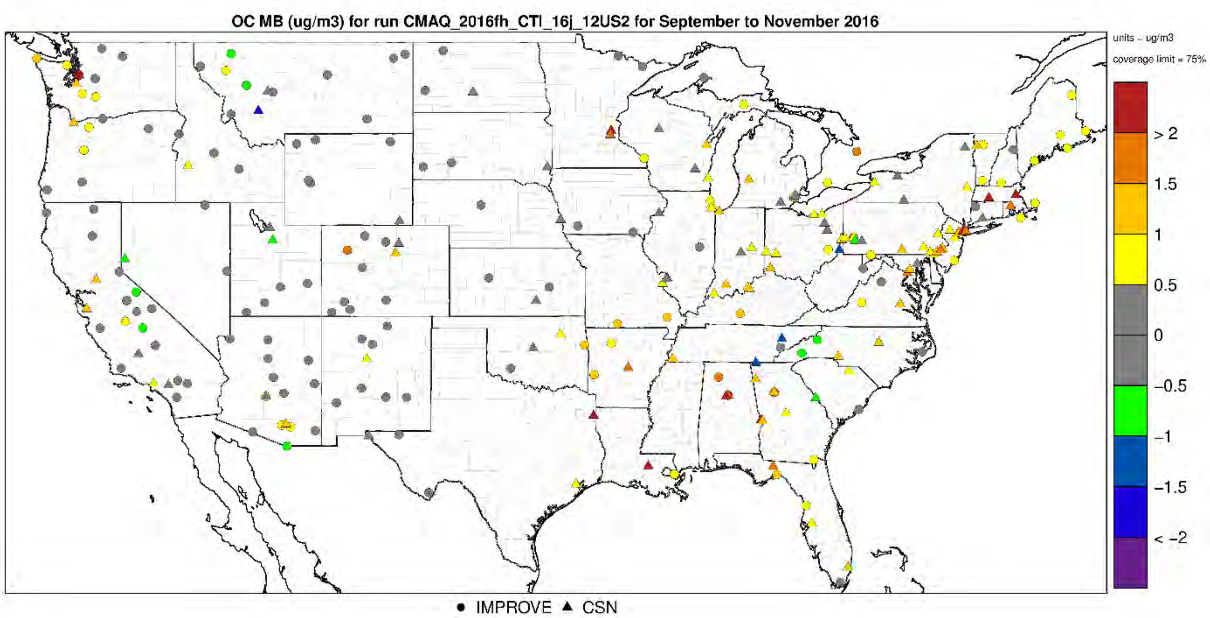

Figure 5-99 Mean Bias (ug/m^3) of organic carbon during fall 2016 at monitoring sites in the modeling domain

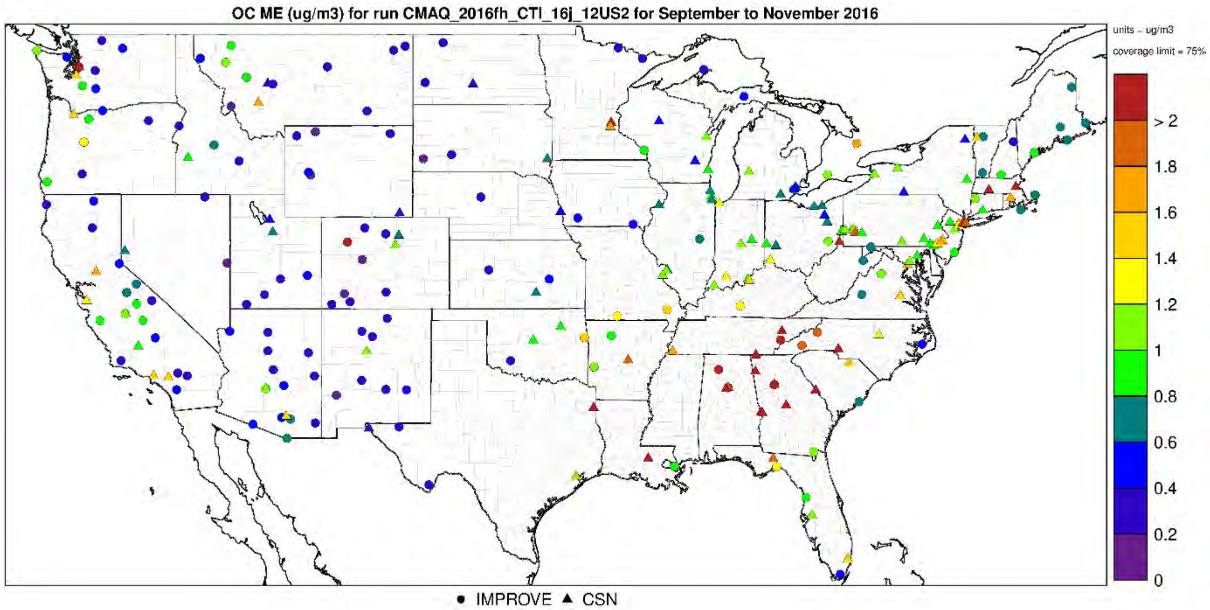

Figure 5-100 Mean Error (ug/m^3) of organic carbon during fall 2016 at monitoring sites in the modeling domain

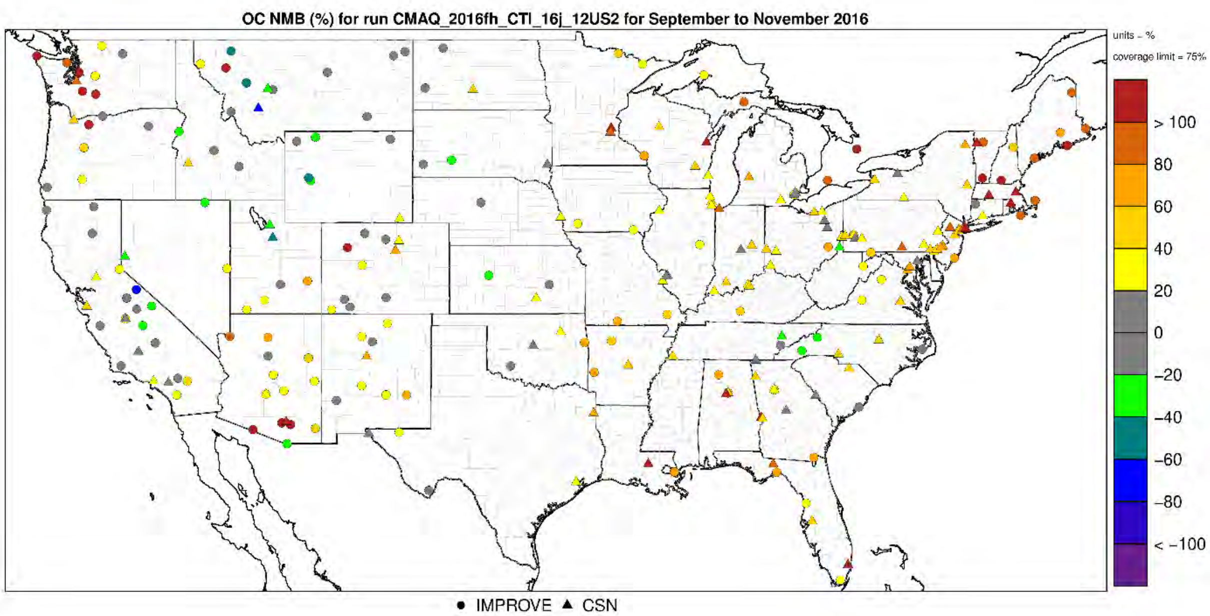

Figure 5-101 Normalized Mean Bias (%) of organic carbon during fall 2016 at monitoring sites in the modeling domain

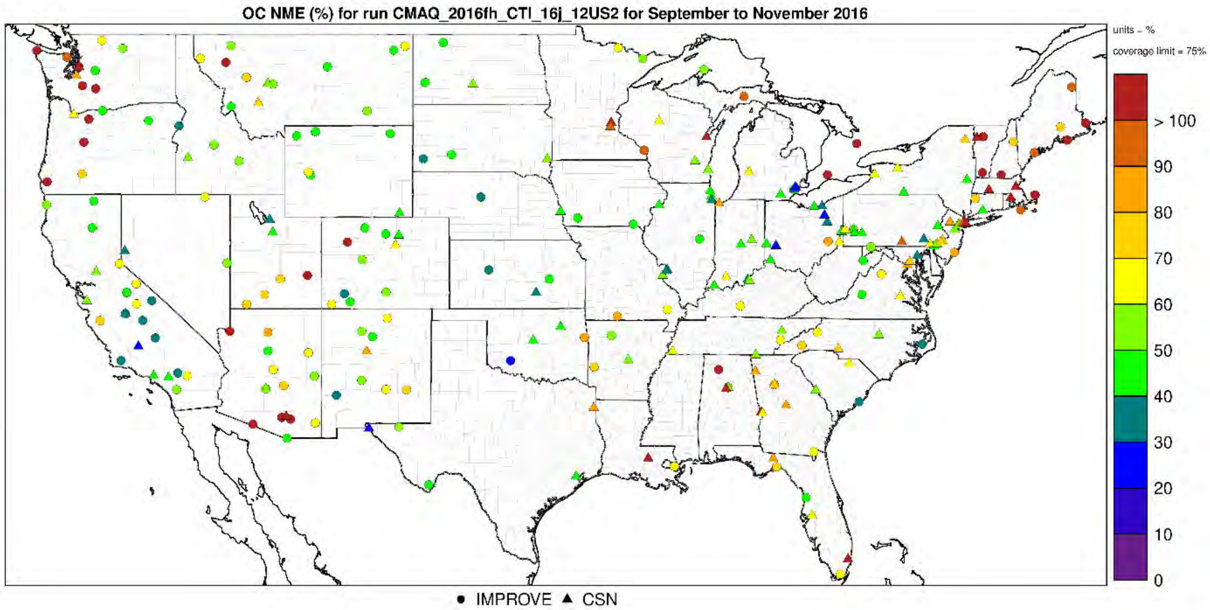

Figure 5-102 Normalized Mean Error (%) of organic carbon during fall 2016 at monitoring sites in the modeling domain

5.4.5 Seasonal Hazardous Air Pollutants Performance

A seasonal operational model performance evaluation for specific hazardous air pollutants (i.e., formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein) was conducted in order to estimate the ability of the CMAQ modeling system to replicate the base year concentrations for the 12 km Continental United States domain. The seasonal model performance results for the 12 km modeling domain are presented below in Table 5-10. Toxic measurements included in the evaluation were taken from the 2016 air toxics archive, https://www.epa.gov/amtic/amtic-air-toxics-data-ambient-monitoring-archive. While most of the data in the archive are from the AQS database including the National Air Toxics Trends Stations (NATTS), additional data (e.g., special studies) are included in the archive but not reported in the AQS. Similar to $PM_{2.5}$ and ozone, the evaluation principally consists of statistical assessments of model versus observed pairs that were paired in time and space on daily basis.

Model predictions of annual formaldehyde, acetaldehyde, benzene and 1,3 butadiene showed relatively small to moderate bias and error percentages when compared to observations. The model yielded larger bias and error results for acrolein based on limited monitoring sites. Model performance for HAPs is not as good as model performance for ozone and $PM_{2.5}$. Technical issues in the HAPs data consist of (1) uncertainties in monitoring methods; (2) limited measurements in time/space to characterize ambient concentrations (“local in nature”); (3) ambient data below method detection limit (MDL); (4) commensurability issues between measurements and model predictions; (5) emissions and science uncertainty issues may also affect model performance; and (6) limited data for estimating intercontinental transport that effects the estimation of boundary conditions (i.e., boundary estimates for some species are much higher than predicted values inside the domain).

As with the national, annual $PM_{2.5}$ and ozone CMAQ modeling, the "acceptability" of model performance was judged by comparing our CMAQ 2016 performance results to the limited performance found in recent regional multi-pollutant model applications.[52, 53, 54] Overall, the mean bias and error (MB and ME), as well as the normalized mean bias and error (NMB and NME) statistics shown below in Table 5-10 indicate that CMAQ-predicted 2016 toxics (i.e., observation vs. model predictions) are within the range of recent regional modeling applications.

Table 5-10 Hazardous Air Toxics Performance Statistics by Season for the 2016 CMAQ Model Simulation

Air Toxic Species	Season	No. of Obs.	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Formaldehyde	Winter	1,417	-1.6	1.6	-61.3	64.1
	Spring	1,512	-1.8	1.9	-59.3	61.4
	Summer	1,872	-1.9	2.1	-43.8	48.3
	Fall	1,418	-1.5	1.7	-46.2	53.3
Acetaldehyde	Winter	1,422	-0.8	0.8	-49.1	53.9
	Spring	1,518	-0.7	0.8	-43.1	51.5
	Summer	1,872	0.0	0.9	2.3	50.7
	Fall	1,400	-0.4	0.9	-20.5	50.3
Benzene	Winter	3,406	-0.1	0.4	-11.9	42.6
	Spring	3,968	-0.2	0.3	-25.8	47.2
	Summer	5,249	0.0	0.2	-11.2	54.9
	Fall	3,858	-0.2	0.4	-21.9	47.9

[52] Phillips, S., K. Wang, C. Jang, N. Possiel, M. Strum, T. Fox, 2007: Evaluation of 2002 Multi-pollutant Platform: Air Toxics, Ozone, and Particulate Matter, 7th Annual CMAS Conference, Chapel Hill, NC, October 6-8, 2008.
[53] Strum, M., Wesson, K., Phillips, S., Cook, R., Michaels, H., Brzezinski, D., Pollack, A., Jimenez, M., Shepard, S. Impact of using in-line emissions on multi-pollutant air quality model predictions at regional and local scales. 17th Annual International Emission Inventory Conference, Portland, Oregon, June 2-5, 2008.
[54] Wesson, K., N. Fann, and B. Timin, 2010: Draft Manuscript: Air Quality and Benefits Model Responsiveness to Varying Horizontal Resolution in the Detroit Urban Area, Atmospheric Pollution Research, Special Issue: Air Quality Modeling and Analysis.

1,3-Butadiene	Winter	2,791	-0.1	0.2	-71.5	87.4
	Spring	2,926	-0.1	0.1	-72.9	89.5
	Summer	2,785	-0.1	0.1	-70.5	88.8
	Fall	2,629	-0.1	0.1	-73.0	88.7
Acrolein	Winter	1,774	-0.5	0.5	-91.8	94.3
	Spring	1,836	-0.5	0.5	-94.8	96.1
	Summer	1,680	-0.7	0.7	-97.0	97.7
	Fall	1,682	-0.6	0.6	-94.4	95.8

5.4.6 Seasonal Nitrate and Sulfate Deposition Performance

Seasonal nitrate and sulfate wet deposition performance statistics for the 12 km Continental U.S. domain are provided in Table 5-11 and Table 5-12. The model predictions for seasonal nitrate deposition generally show under predictions for the continental U.S. NADP sites (NMB values range from -13.1% to -27.5%). Sulfate deposition performance shows the similar under predictions (NMB values range from -21.5% to 41.9%). The errors for both annual nitrate and sulfate are relatively moderate with values ranging from 51.5% to 59.3% which reflect scatter in the model predictions versus observation comparison.

Table 5-11 Nitrate Wet Deposition Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2016 CMAQ Model Simulation

Climate Region	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	Winter	578	-0.1	0.1	-39.3	54.2
	Spring	618	0.0	0.1	-12.1	43.4
	Summer	649	0.0	0.1	-24.7	51.7
	Fall	647	0.0	0.1	-1.3	49.7
Ohio Valley	Winter	297	0.0	0.1	-0.5	52.1
	Spring	300	0.0	0.1	-6.6	33.0
	Summer	309	-0.1	0.1	-31.3	51.1
	Fall	288	0.0	0.1	5.2	52.3
Upper Midwest	Winter	275	0.0	0.1	-36.7	64.9
	Spring	277	0.0	0.1	-30.2	48.5
	Summer	292	-0.1	0.1	-33.2	46.7

Climate Region	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
	Fall	301	0.0	0.1	-17.8	48.1
Southeast	Winter	350	0.0	0.0	-3.6	51.8
	Spring	376	0.0	0.1	-12.6	46.8
	Summer	403	-0.1	0.1	-33.3	51.1
	Fall	377	0.0	0.0	-17.7	60.1
South	Winter	231	0.0	0.0	15.5	59.9
	Spring	252	0.0	0.1	-8.9	45.9
	Summer	270	-0.1	0.1	-41.6	54.5
	Fall	270	0.0	0.0	-17.3	55.2
Southwest	Winter	300	0.0	0.0	-79.2	83.4
	Spring	322	0.0	0.1	-69.8	80.2
	Summer	293	0.0	0.1	-38.9	57.6
	Fall	334	0.0	0.0	-48.8	73.8
Northern Rockies	Winter	216	0.0	0.0	-64.5	91.5
	Spring	251	0.0	0.1	-50.5	59.1
	Summer	226	0.0	0.1	-38.7	50.7
	Fall	237	0.0	0.0	-38.5	64.4
Northwest	Winter	121	0.0	0.0	-2.7	52.8
	Spring	141	0.0	0.0	-4.0	58.6
	Summer	138	0.0	0.0	0.8	77.3
	Fall	145	0.0	0.0	19.3	62.6
West	Winter	151	0.0	0.0	-33.3	56.0
	Spring	151	0.0	0.0	5.7	83.5
	Summer	161	0.0	0.0	-20.5	>100
	Fall	160	0.0	0.0	-17.2	74.9

Table 5-12 Sulfate Wet Deposition Performance Statistics by Climate Region, by Season, and by Monitoring Network for the 2016 CMAQ Model Simulation

Climate Region	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
Northeast	Winter	578	0.0	0.1	-41.2	57.6
	Spring	618	0.0	0.0	-17.6	44.8
	Summer	649	0.0	0.1	-14.4	56.3
	Fall	647	0.0	0.1	-19.1	54.2
Ohio Valley	Winter	297	0.0	0.1	-24.8	50.2
	Spring	300	0.0	0.1	-12.6	34.9
	Summer	309	0.0	0.1	-20.8	50.9
	Fall	288	0.0	0.0	-11.9	51.6
Upper Midwest	Winter	275	0.0	0.0	-37.6	59.5
	Spring	277	0.0	0.0	-29.4	49.9
	Summer	292	0.0	0.1	-22.6	49.2
	Fall	301	0.0	0.0	-33.0	53.8
Southeast	Winter	350	0.0	0.1	-24.3	51.8
	Spring	376	0.0	0.1	-23.8	53.8
	Summer	403	0.0	0.1	-27.3	54.5
	Fall	377	0.0	0.0	-21.0	63.5
South	Winter	231	0.0	0.0	-13.7	50.2
	Spring	252	-0.1	0.1	-38.0	52.3
	Summer	270	-0.1	0.1	-44.4	62.4
	Fall	270	0.0	0.0	-35.8	60.4
Southwest	Winter	300	0.0	0.0	-77.1	84.6
	Spring	322	0.0	0.0	-65.6	78.3
	Summer	293	0.0	0.0	-27.8	60.0
	Fall	334	0.0	0.0	-61.7	75.5
Northern Rockies	Winter	216	0.0	0.0	-62.8	87.7
	Spring	251	0.0	0.0	-50.1	59.5
	Summer	226	0.0	0.0	-30.1	52.7

Climate Region	Season	No. of Obs	MB (ug/m^3)	ME (ug/m^3)	NMB (%)	NME (%)
	Fall	237	0.0	0.0	-48.1	65.6
Northwest	Winter	121	0.0	0.0	40.0	75.1
	Spring	141	0.0	0.0	20.2	65.3
	Summer	138	0.0	0.0	43.3	>100
	Fall	145	0.0	0.1	51.8	92.5
West	Winter	151	0.0	0.0	55.8	99.6
	Spring	151	0.0	0.0	30.1	95.1
	Summer	161	0.0	0.0	-31.1	93.0
	Fall	160	0.0	0.0	3.2	88.1

5.5 Model Simulation Scenarios

As part of our analysis for this rulemaking, the CMAQ modeling system was used to calculate 8-hour ozone concentrations, daily and annual $PM_{2.5}$ concentrations, annual NO_2 concentrations, annual CO concentrations, annual and seasonal (summer and winter) air toxics concentrations, visibility levels and annual nitrogen deposition total levels for each of the following emissions scenarios:

- 2016 base year
- 2045 proposal reference case
- 2045 proposal control case

As mentioned above, the inventories used for the air quality modeling and the proposal inventories are consistent in many ways but there are some differences. Chapter 5 of the DRIA has more detail on the differences between the air quality and proposal inventories.

We use the predictions from the model in a relative sense by combining the 2016 base-year predictions with predictions from each future-year scenario and applying these modeled ratios to ambient air quality observations to estimate 8-hour ozone concentrations, daily and annual $PM_{2.5}$ concentrations, annual NO_2 concentrations, annual CO concentrations, and visibility impairment for each of the 2045 scenarios. The ambient air quality observations are average conditions, on a site-by-site basis, for a period centered around the model base year (i.e., 2014-2018).

The projected daily and annual $PM_{2.5}$ design values were calculated using the Speciated Modeled Attainment Test (SMAT) approach. The SMAT uses a Federal Reference Method (FRM) mass construction methodology that results in reduced nitrates (relative to the amount measured by routine speciation networks), higher mass associated with sulfates (reflecting water included in FRM measurements), and a measure of organic carbonaceous mass that is derived from the difference between measured $PM_{2.5}$ and its non-carbon components. This characterization of $PM_{2.5}$ mass also reflects crustal material and other minor constituents. The resulting characterization provides a complete mass balance. It does not have any unknown mass that is sometimes presented as the difference between measured $PM_{2.5}$ mass and the characterized chemical components derived from routine speciation measurements. However, the assumption that all mass difference is organic carbon has not been validated in many areas of the U.S. The SMAT methodology uses the following $PM_{2.5}$ species components: sulfates, nitrates, ammonium, organic carbon mass, elemental carbon, crustal, water, and blank mass (a fixed value of 0.5 $\mu g/m^3$). More complete details of the SMAT procedures can be found in the report "Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)."[55] For this analysis, several datasets and techniques were updated. These changes are fully described within the technical support document for the Final Transport Rule AQM TSD.[56] The projected 8-hour ozone design values were calculated using the approach identified in EPA's guidance on air quality modeling attainment demonstrations.[57]

Additionally, we conducted an analysis to compare the absolute and percent differences between the future year reference and control cases for annual and seasonal formaldehyde, acetaldehyde, benzene, and naphthalene, as well as annual nitrate deposition. These data were not compared in a relative sense due to the limited observational data available.

6 Air Quality Modeling Results

The draft RIA includes maps that present the impact of the proposed Option 1 on projected ozone and $PM_{2.5}$ design values, projected CO, NO_2, and air toxics concentrations, and projected nitrogen deposition. In this TSD we present annual reference and control case maps for CO, NO_2, air toxics, and nitrogen deposition as well as seasonal difference maps for air toxics and visibility levels at Mandatory Class I Federal Areas.

6.1 Annual Reference and Control Case Maps

The following section presents maps of ambient concentrations of CO, NO_2, acetaldehyde, benzene, formaldehyde and naphthalene and total nitrogen deposition in the 2045 reference case (without the proposed rule) and the 2045 control case (with the proposed Option 1).

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[55] U.S. EPA, 2004, Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT)- Updated 11/8/04.
[56] U.S. EPA, 2011, Final Cross State Air Pollution Rule Air Quality Modeling TSD.
[57] U.S. EPA, 2018. Modeling Guidance For Demonstrating Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze; EPA-454/R-18-009; Research Triangle Park, NC; November 2018.

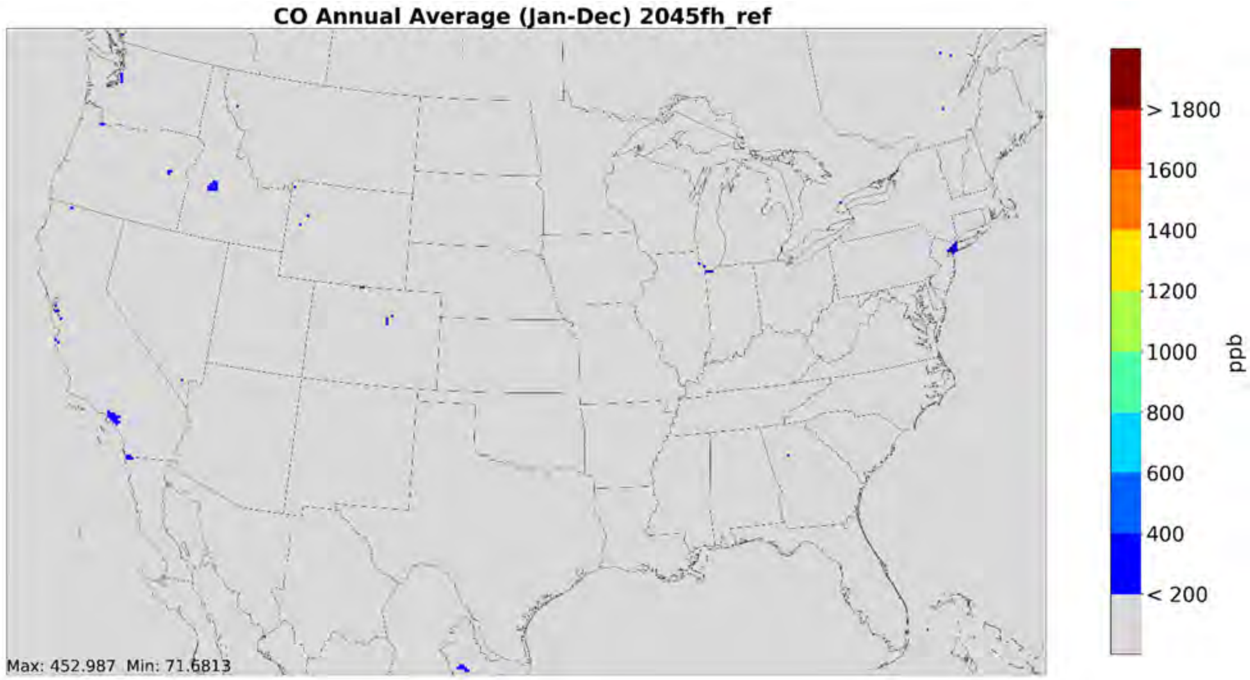

Figure 6-1 Projected Annual Average CO Concentrations in 2045 without the Proposed Rule (ppb)

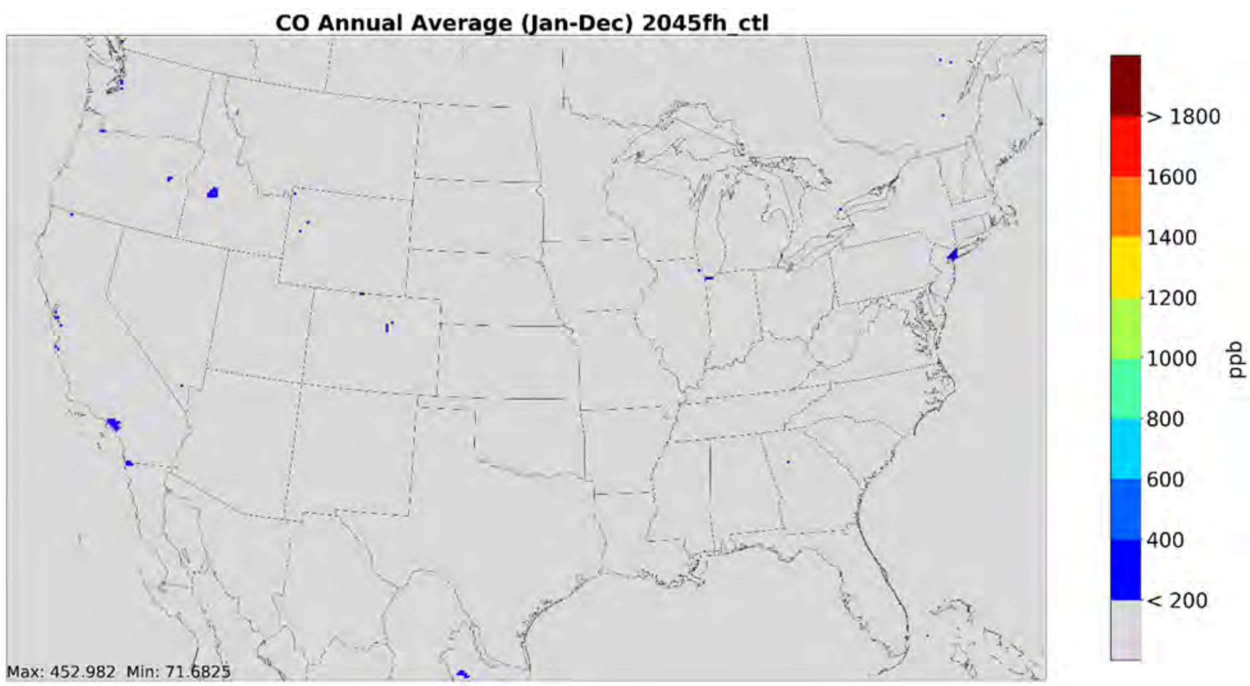

Figure 6-2 Projected Annual Average CO Concentrations in 2045 with the Proposed Option 1 (ppb)

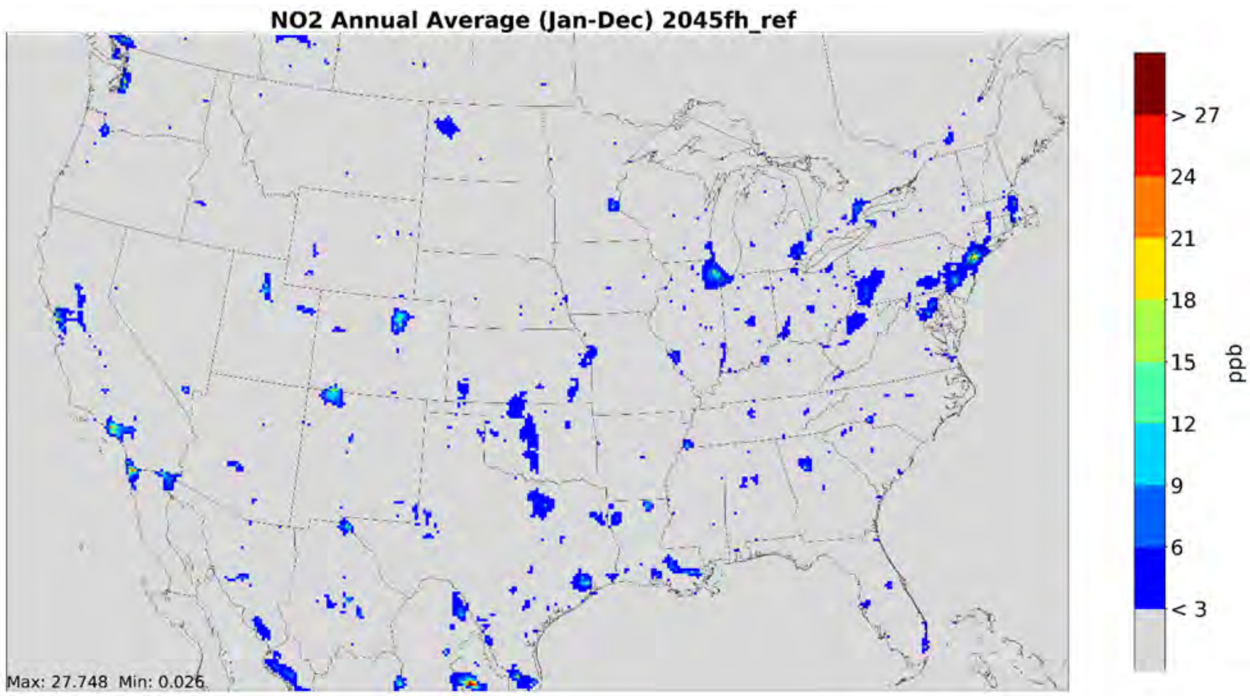

Figure 6-3 Projected Annual Average NO_2 Concentrations in 2045 without the Proposed Rule (ppb)

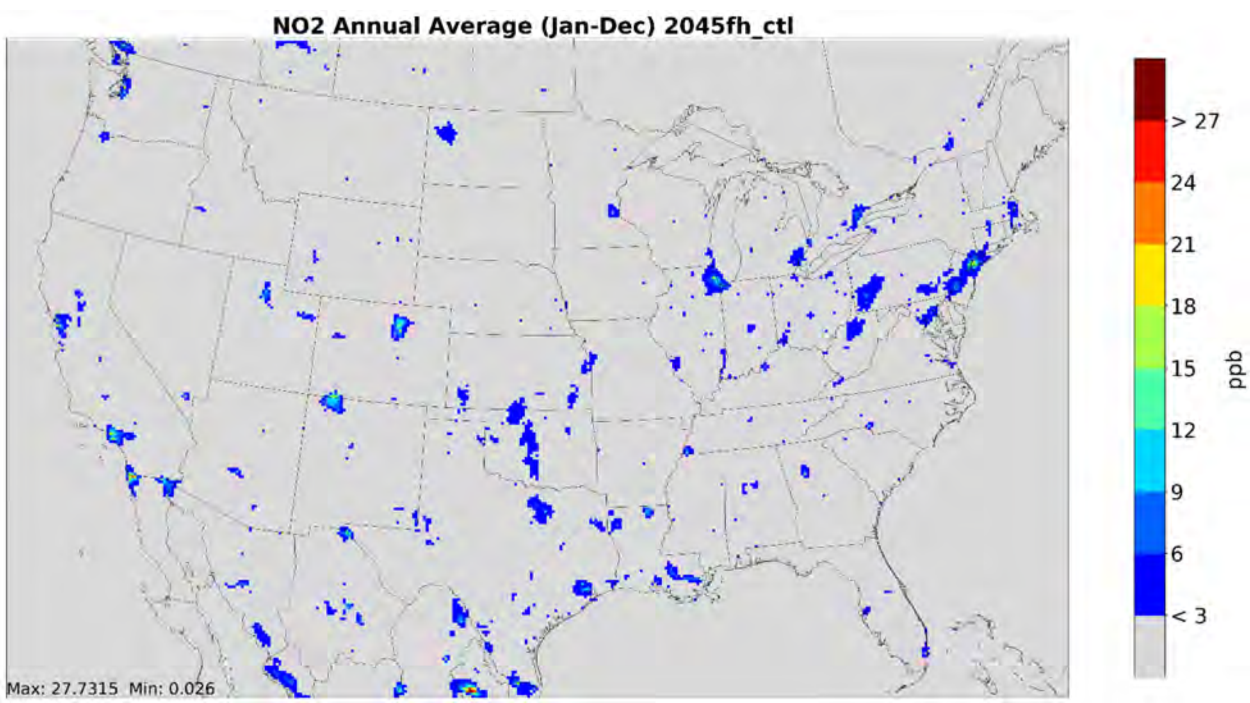

Figure 6-4 Projected Annual Average NO_2 Concentrations in 2045 with the Proposed Option 1 (ppb)

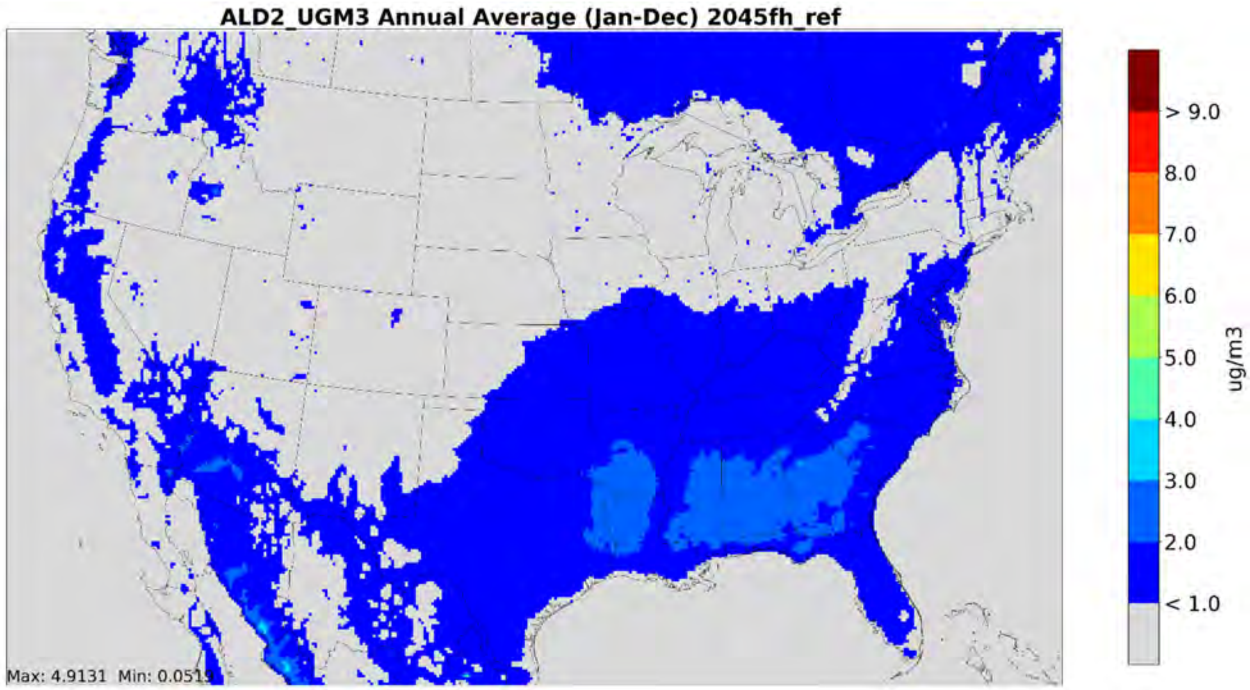

Figure 6-5 Projected Annual Average Acetaldehyde Concentrations in 2045 without the Proposed Rule (ug/m^3)

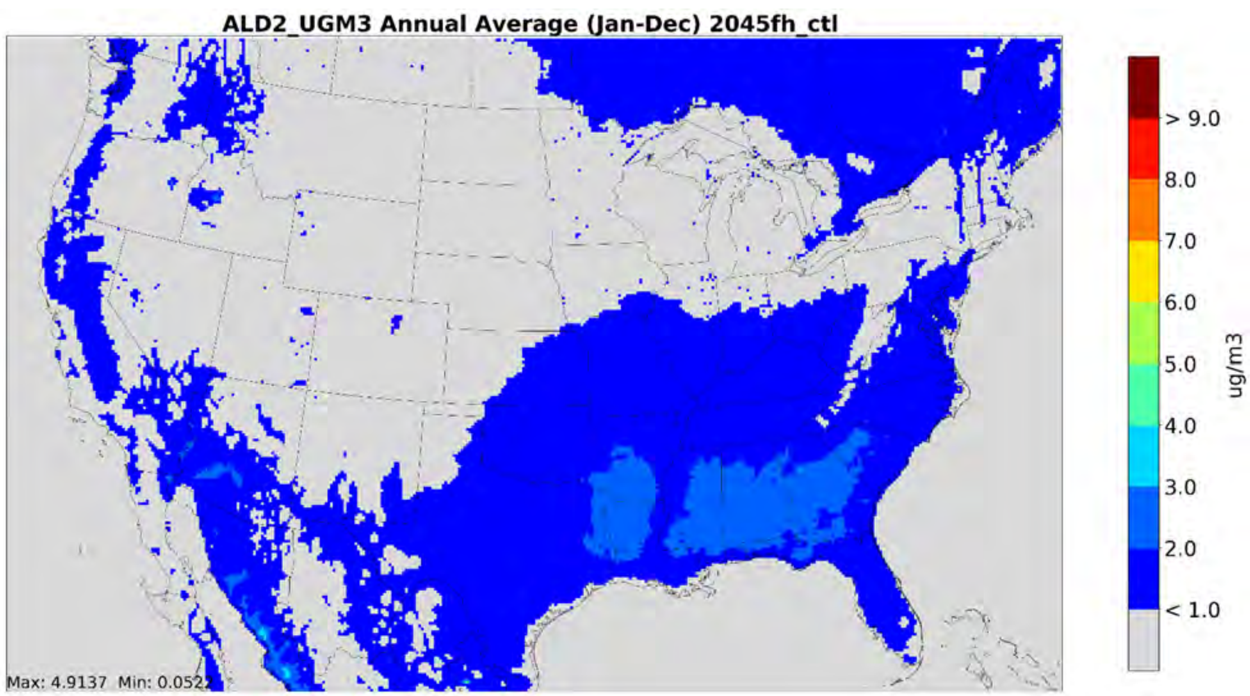

Figure 6-6 Projected Annual Average Acetaldehyde Concentrations in 2045 with the Proposed Option 1 (ug/m^3)

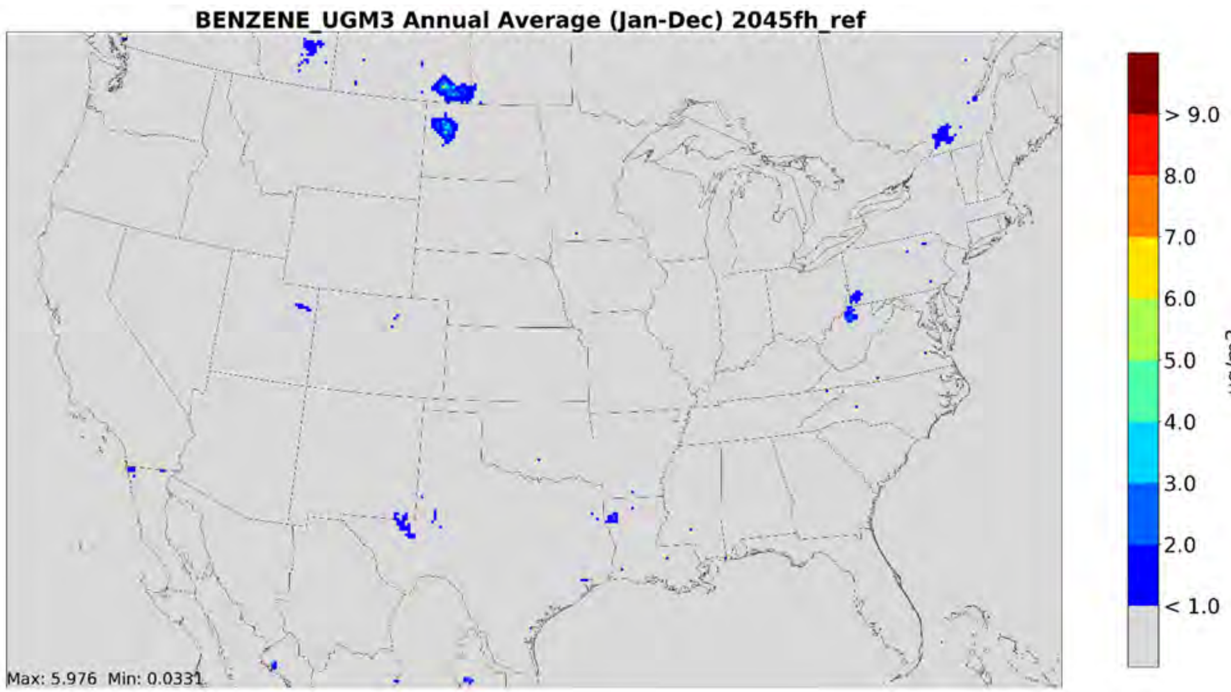

Figure 6-7 Projected Annual Average Benzene Concentrations in 2045 without the Proposed Rule (ug/m^3)

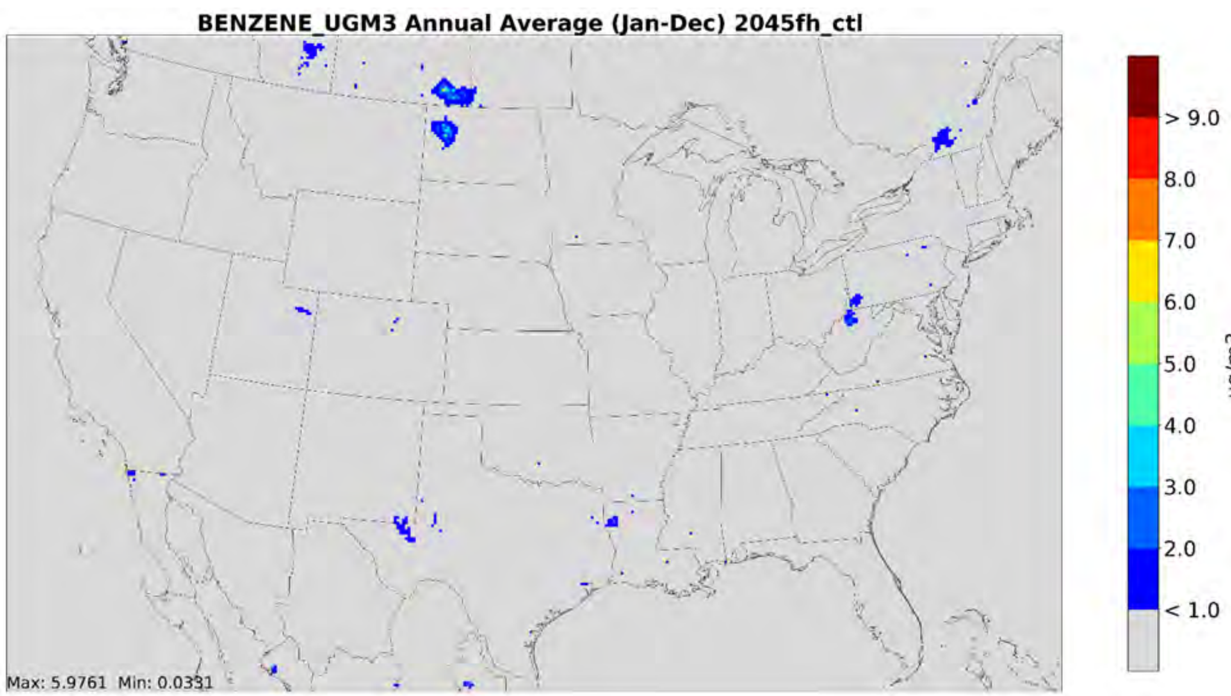

Figure 6-8 Projected Annual Average Benzene Concentrations in 2045 with the Proposed Option 1 (ug/m^3)

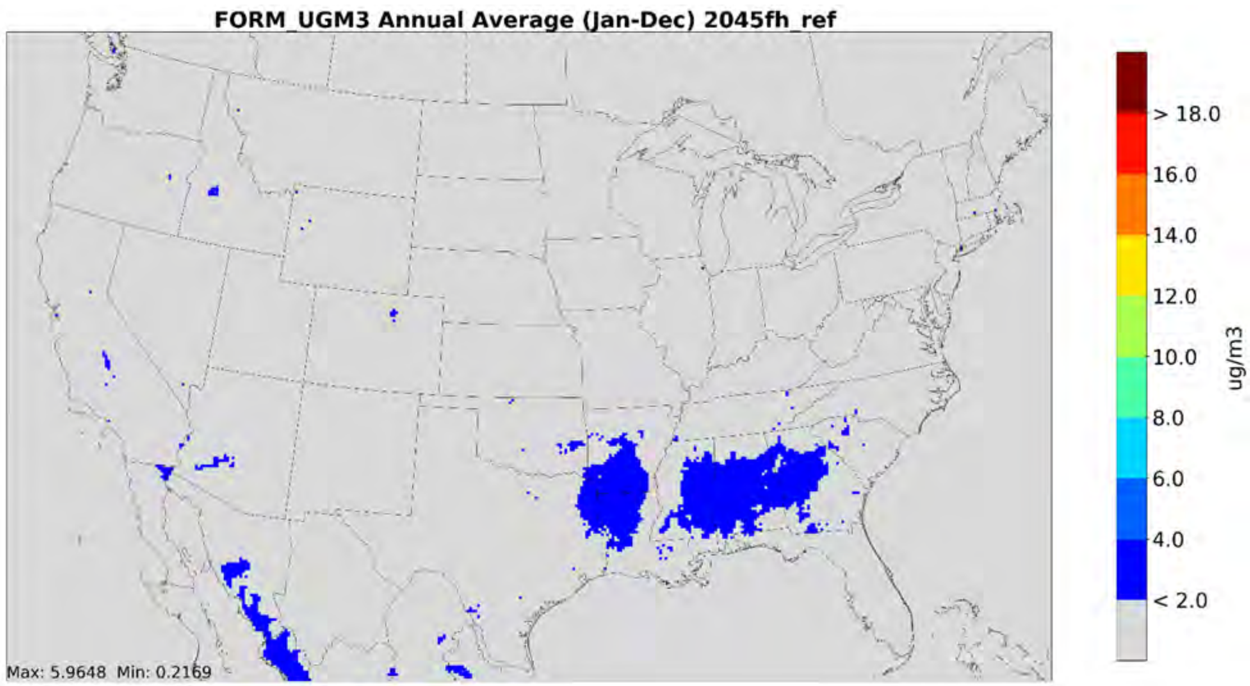

Figure 6-9 Projected Annual Average Formaldehyde Concentrations in 2045 without the Proposed Rule (ug/m^3)

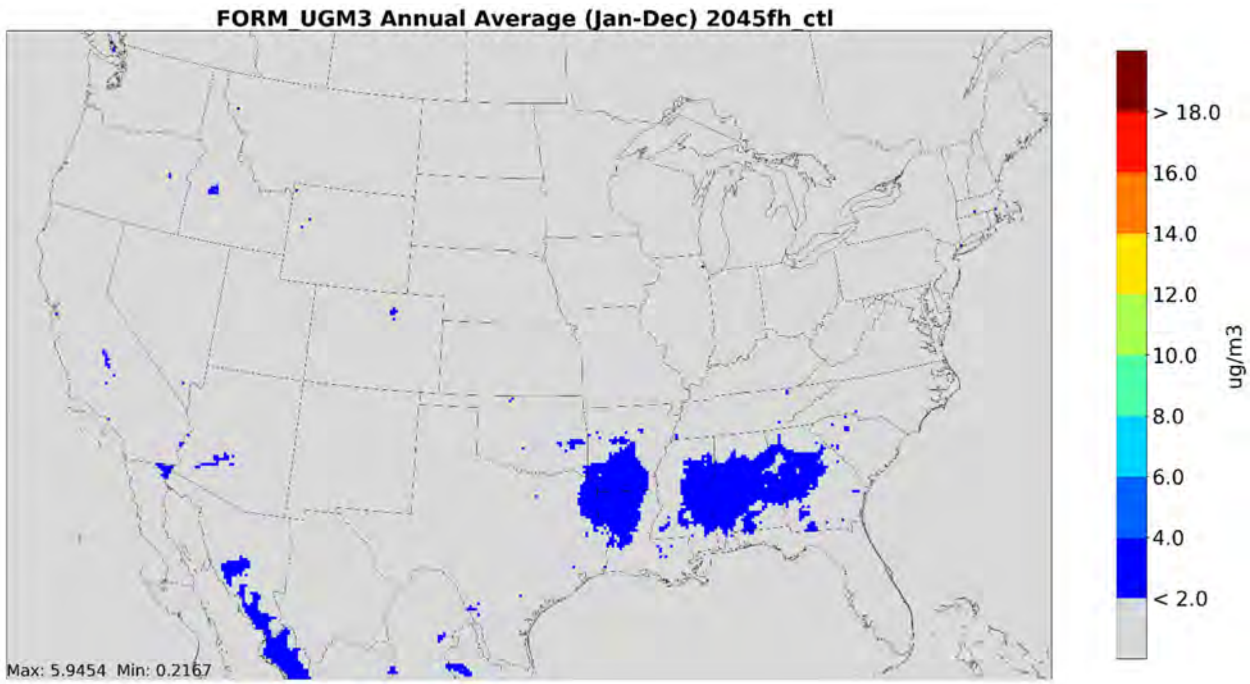

Figure 6-10 Projected Annual Average Formaldehyde Concentrations in 2045 with the Proposed Option 1 (ug/m^3)

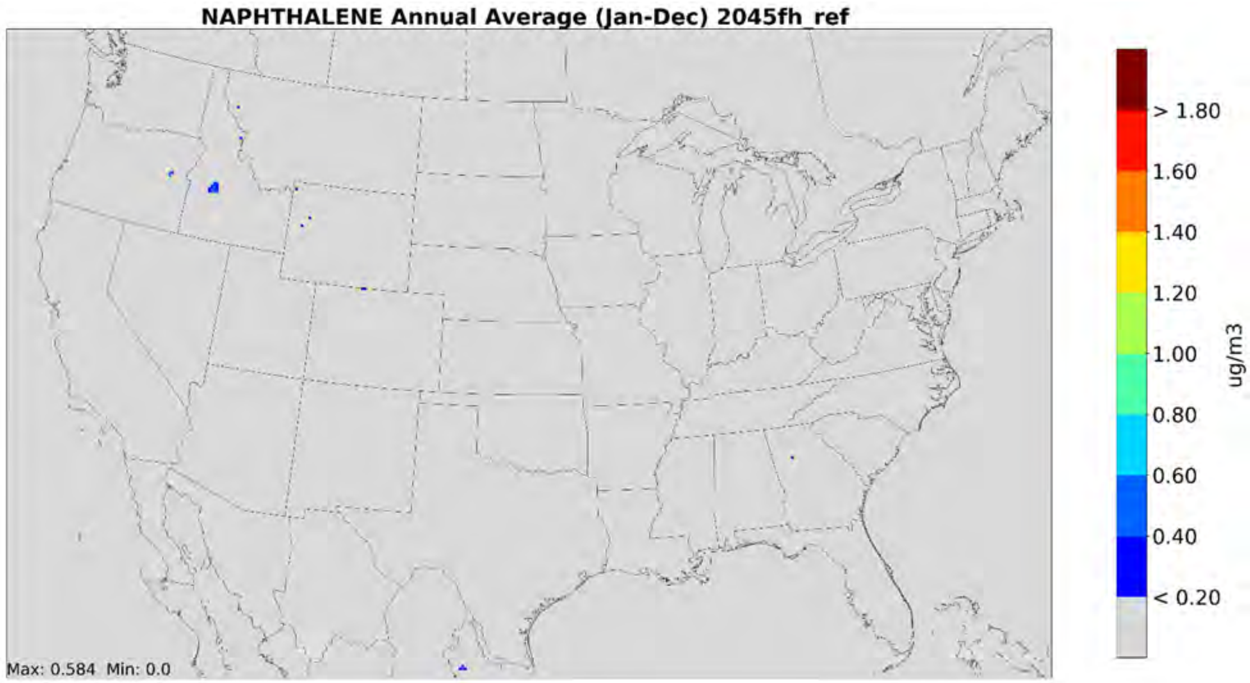

Figure 6-11 Projected Annual Average Naphthalene Concentrations in 2045 without the Proposed Rule (ug/m^3)

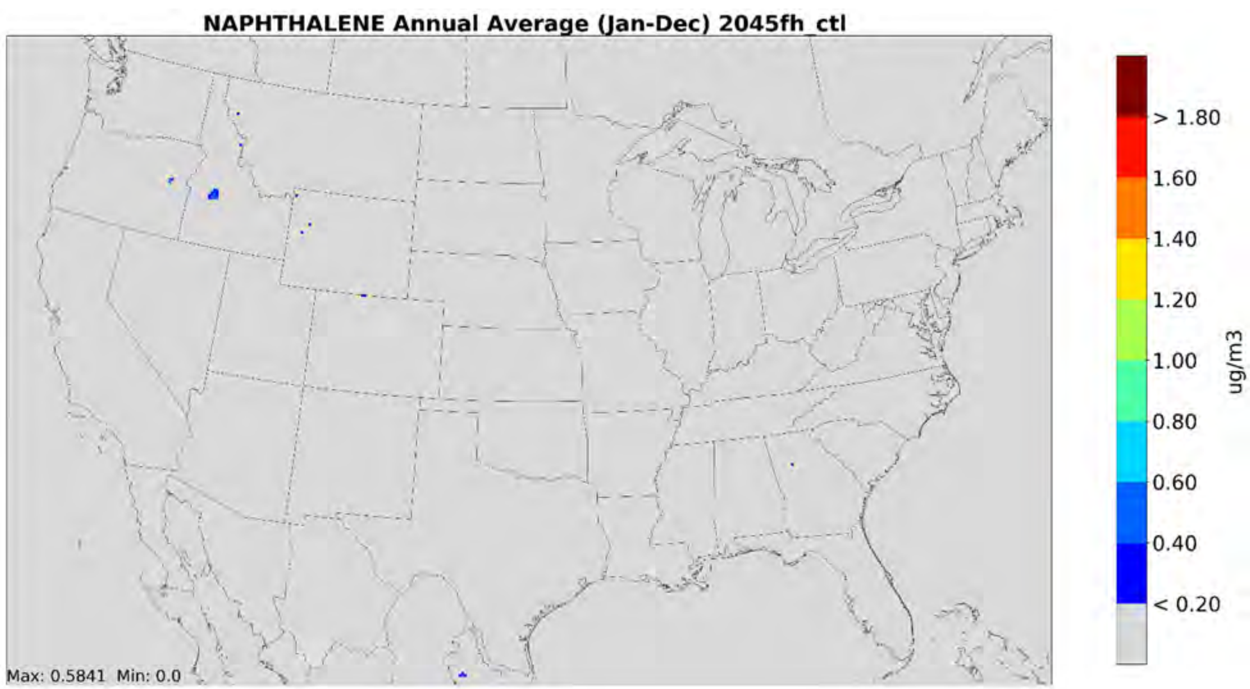

Figure 6-12 Projected Annual Average Naphthalene Concentrations in 2045 with the Proposed Option 1 (ug/m^3)

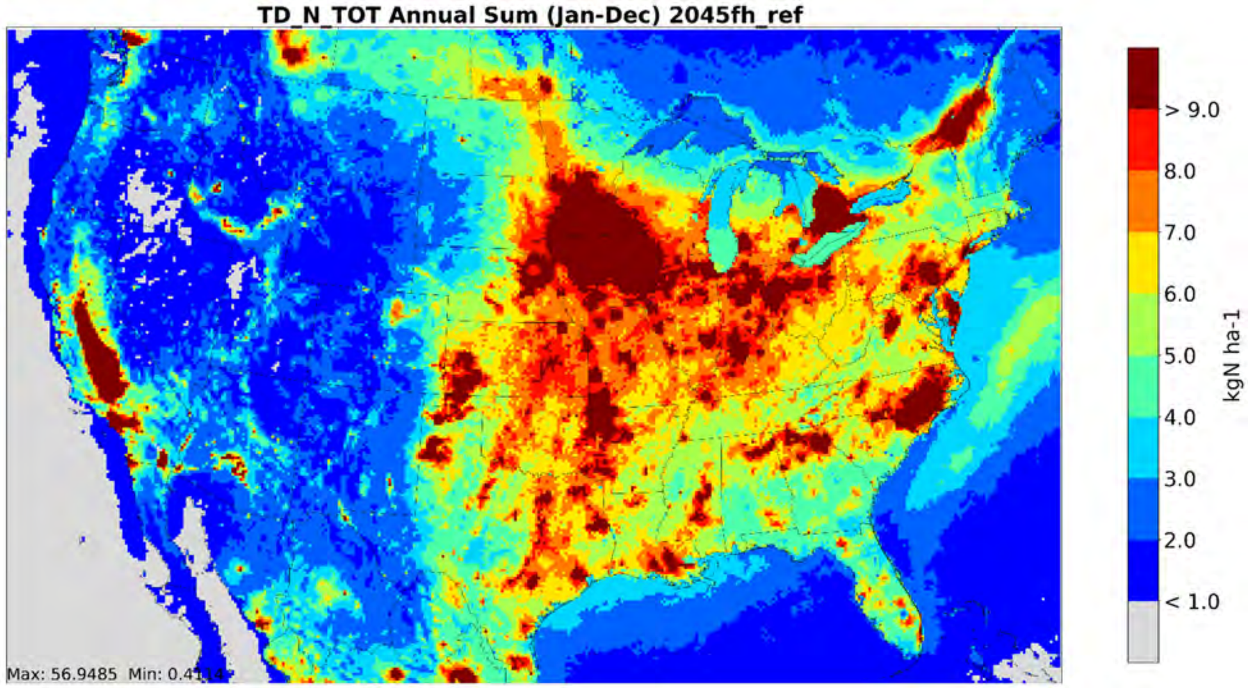

Figure 6-13 Projected Annual Nitrogen Deposition in 2045 without the Proposed Rule (kg N/ha)

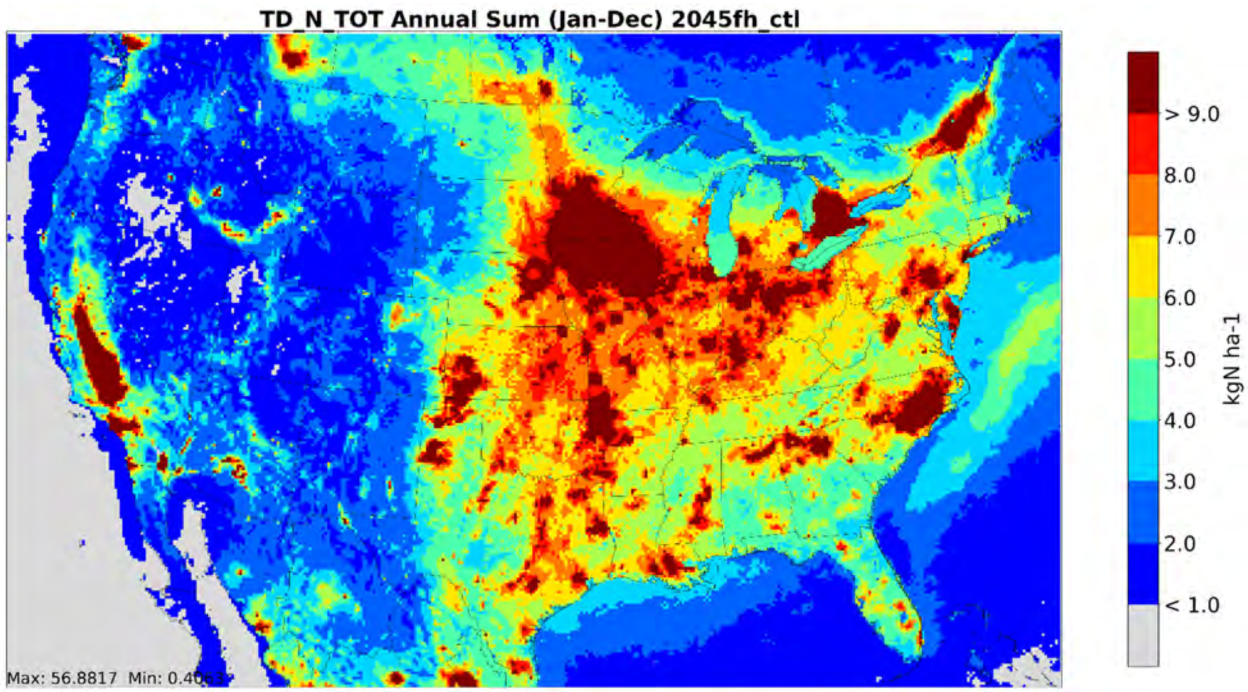

Figure 6-14 Projected Annual Nitrogen Deposition in 2045 with the Proposed Option 1 (kg N/ha)

6.2 Seasonal Reference and Control Case Maps

The following section presents maps of January and July monthly average ambient concentrations of acetaldehyde, benzene, formaldehyde and naphthalene in the 2045 reference case (without the proposed rule) and the 2045 control case (with the proposed Option 1).

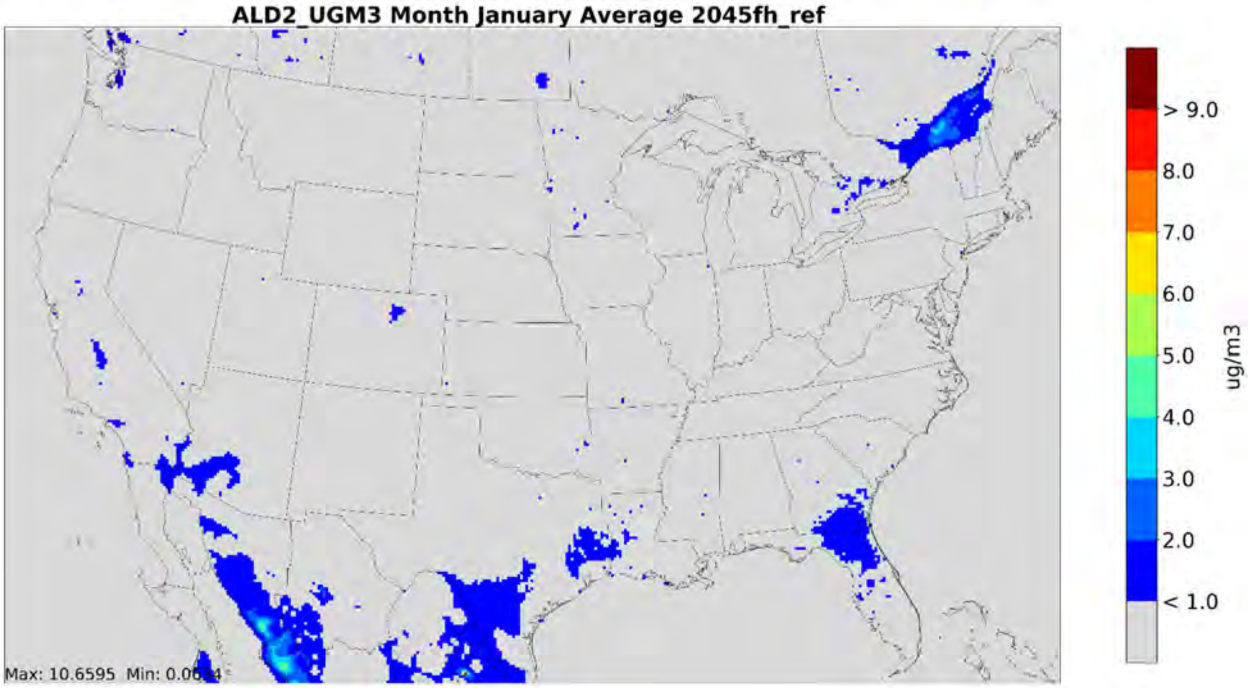

Figure 6-15 Projected January Average Acetaldehyde Concentrations in 2045 without the Proposed Rule (ug/m³)

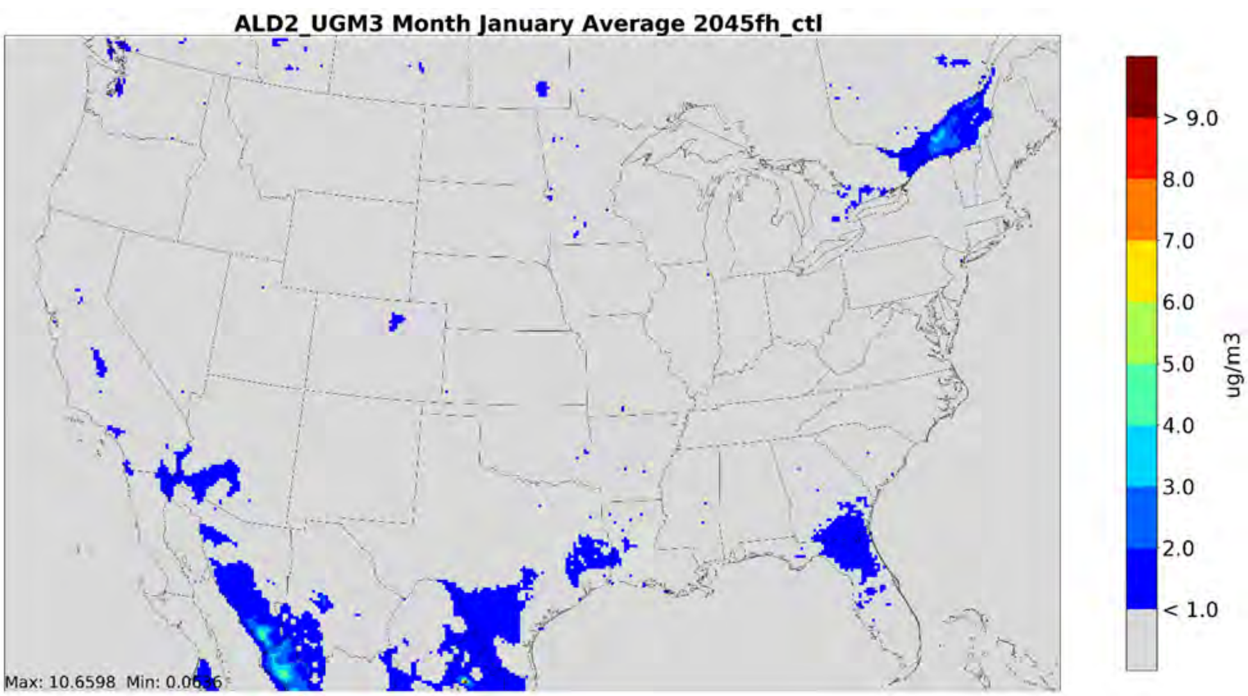

Figure 6-16 Projected January Average Acetaldehyde Concentrations in 2045 with the Proposed Option 1 (ug/m³)

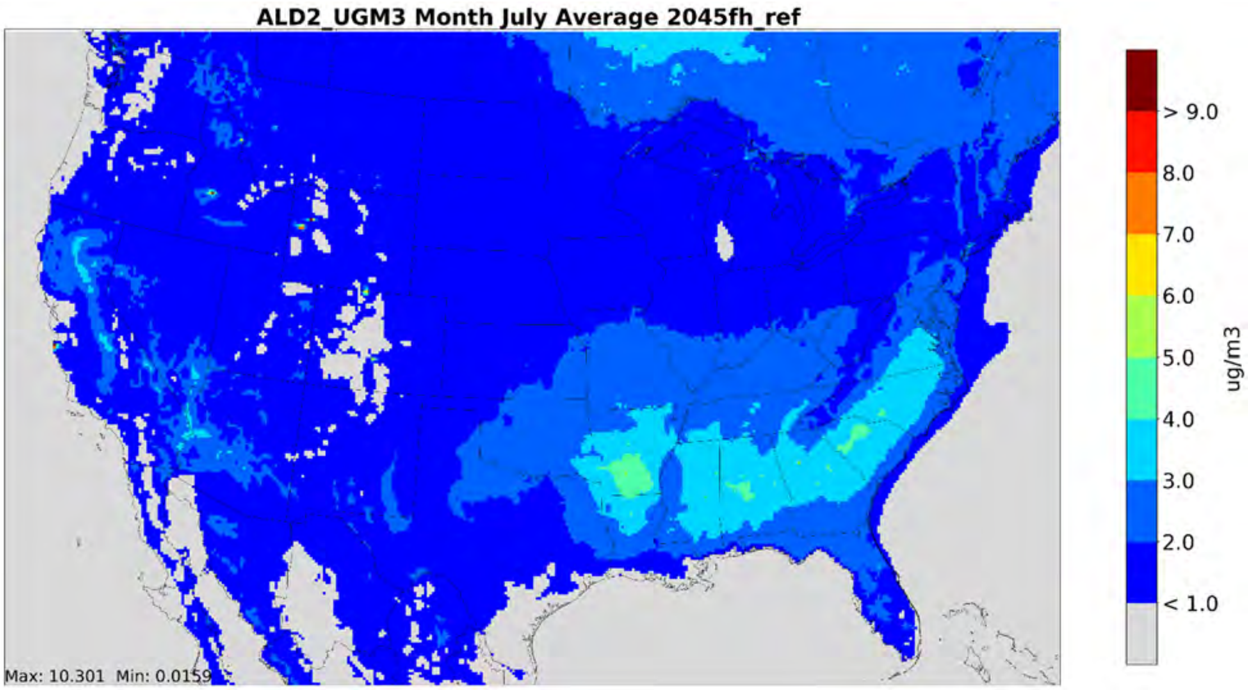

Figure 6-17 Projected July Average Acetaldehyde Concentrations in 2045 without the Proposed Rule (ug/m^3)

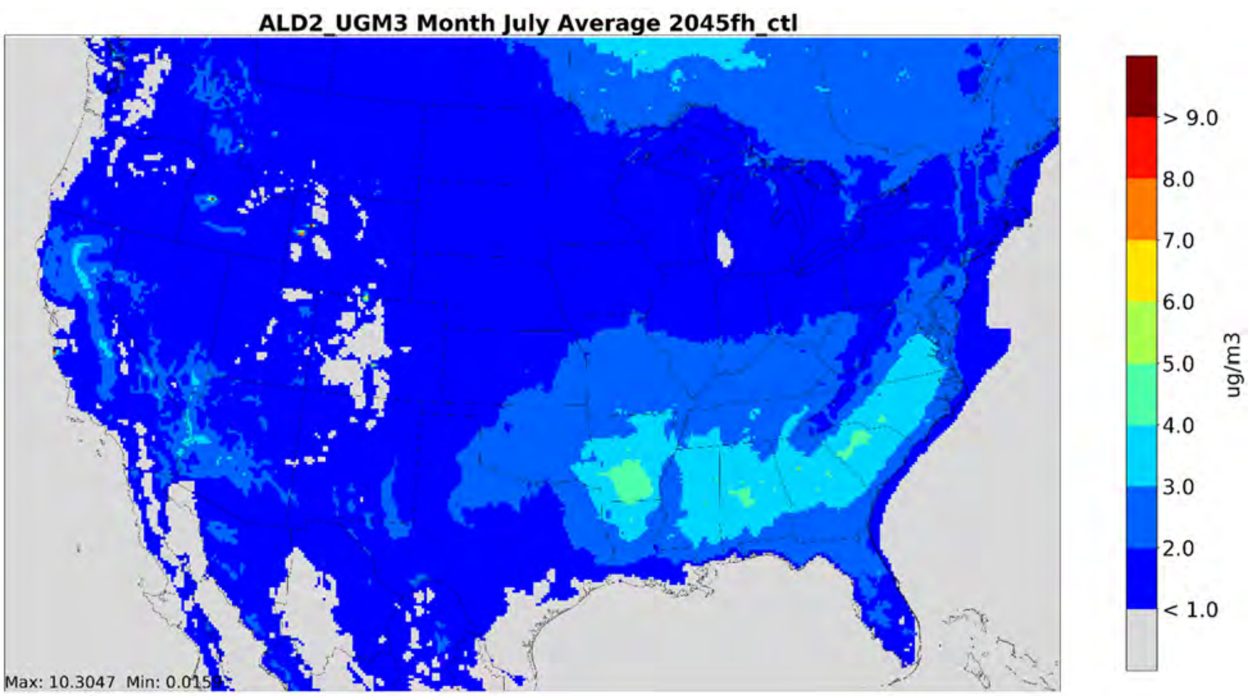

Figure 6-18 Projected July Average Acetaldehyde Concentrations in 2045 with the Proposed Option 1 (ug/m^3)

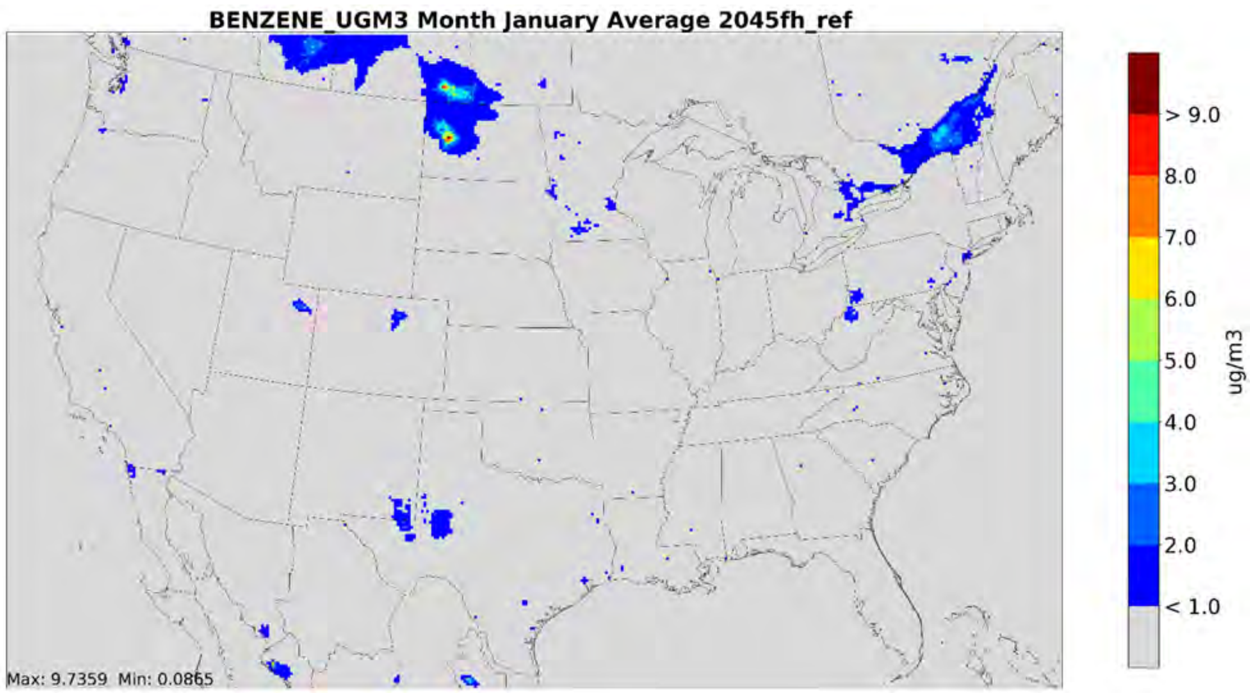

Figure 6-19 Projected January Average Benzene Concentrations in 2045 without the Proposed Rule (ug/m^3)

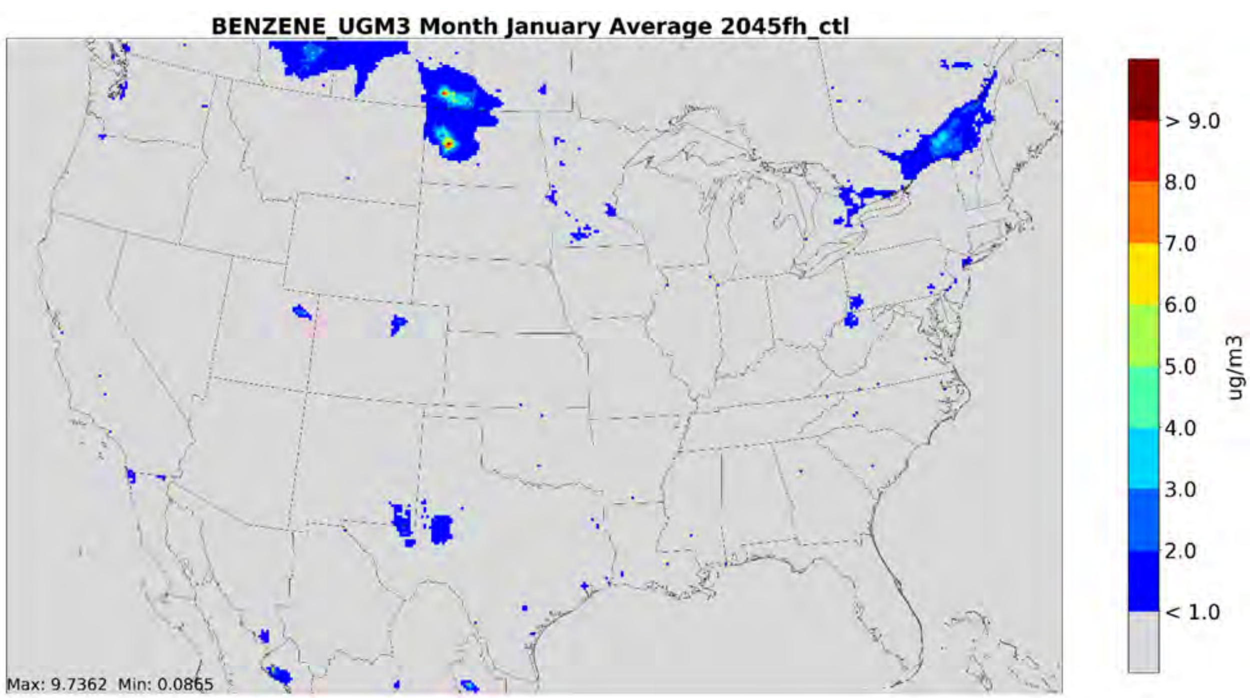

Figure 6-20 Projected January Average Benzene Concentrations in 2045 with the Proposed Option 1 (ug/m^3)

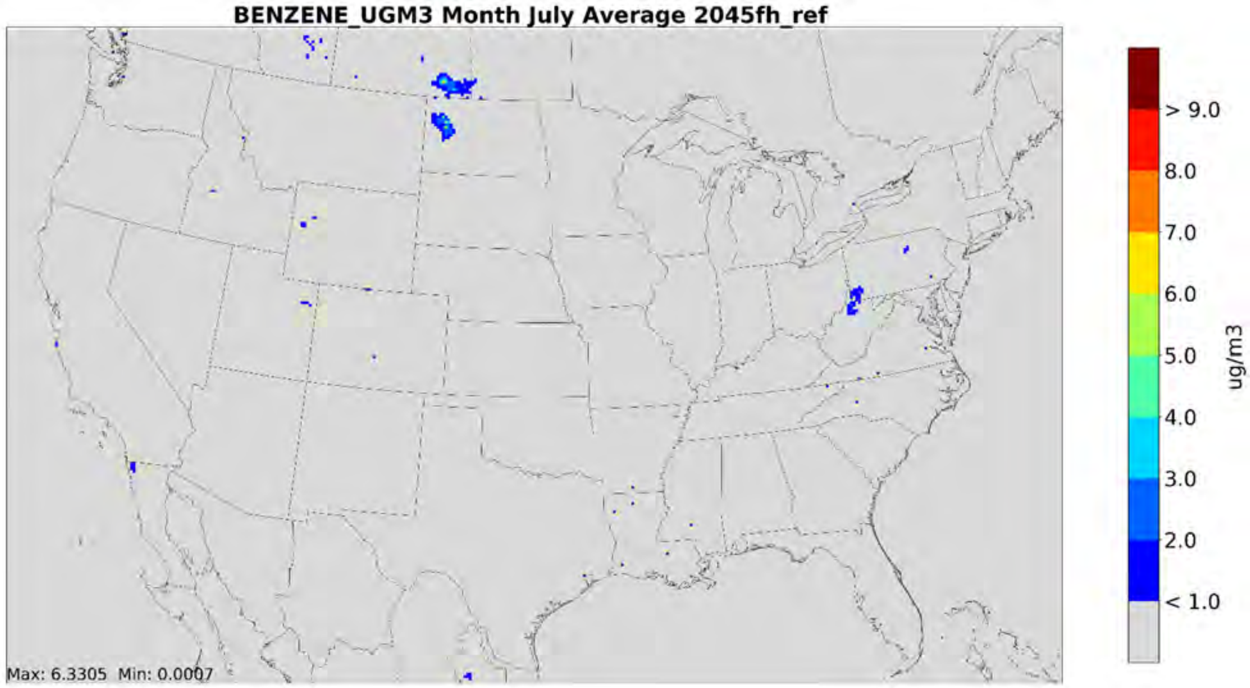

Figure 6-21 Projected July Average Benzene Concentrations in 2045 without the Proposed Rule (ug/m^3)

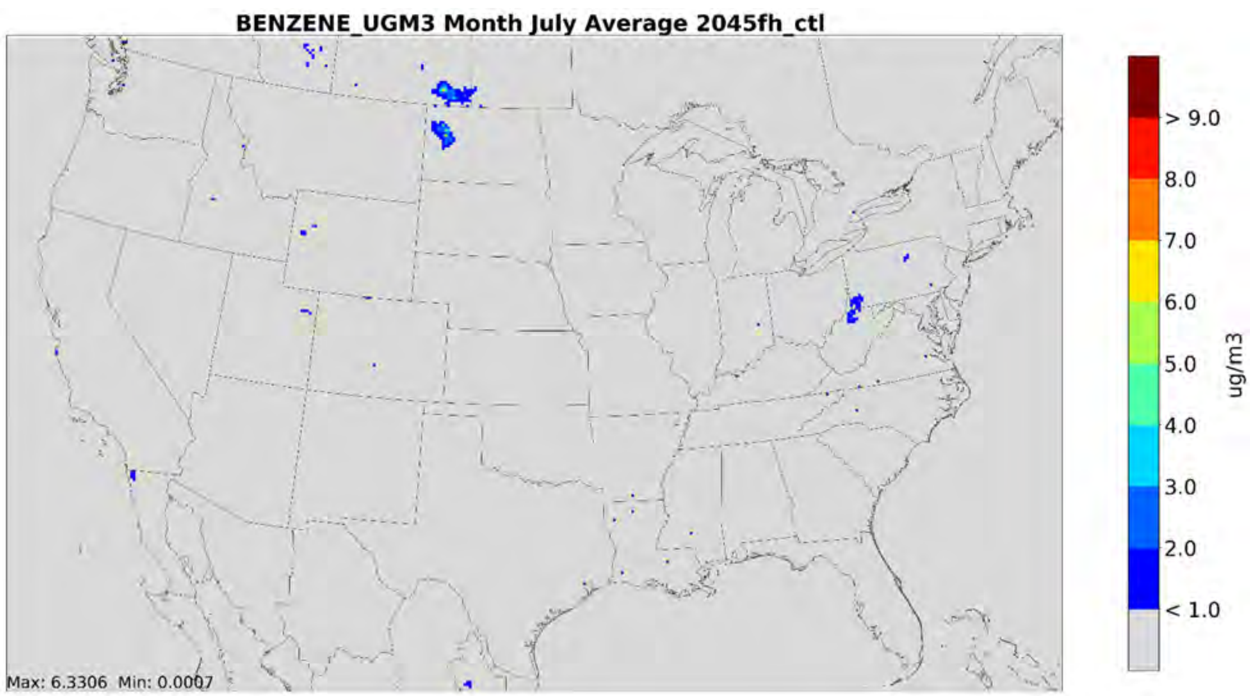

Figure 6-22 Projected July Average Benzene Concentrations in 2045 with the Proposed Option 1 (ug/m^3)

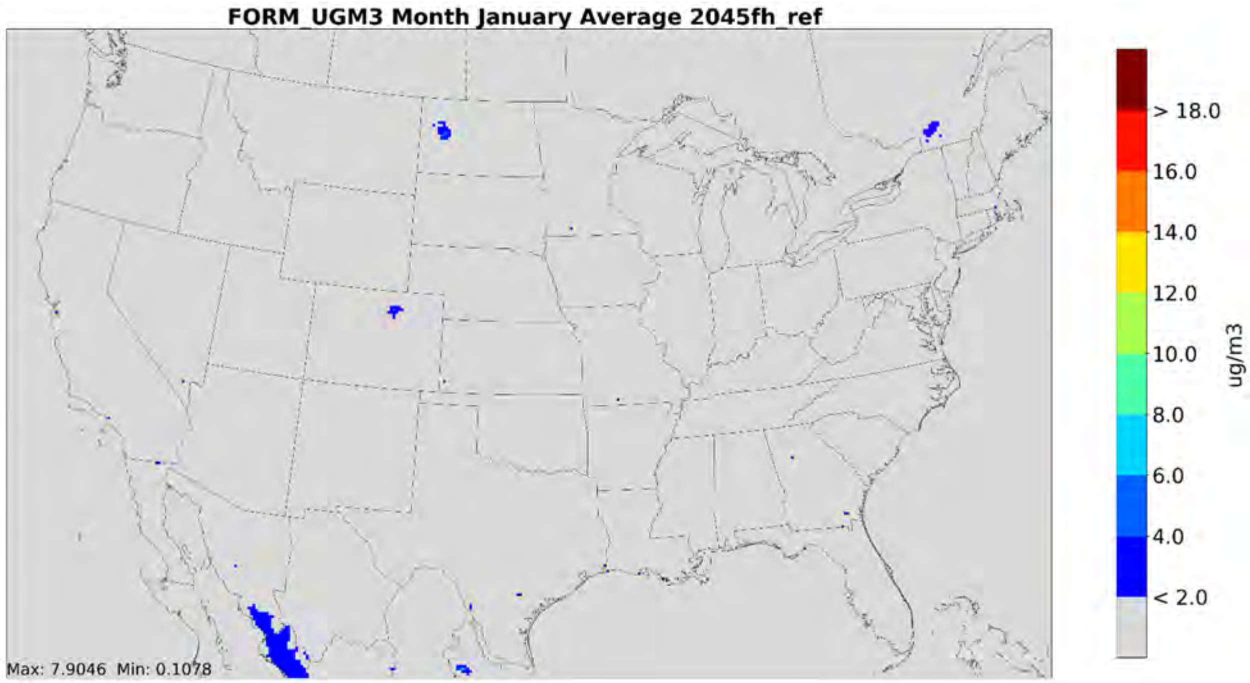

Figure 6-23 Projected January Average Formaldehyde Concentrations in 2045 without the Proposed Rule (ug/m^3)

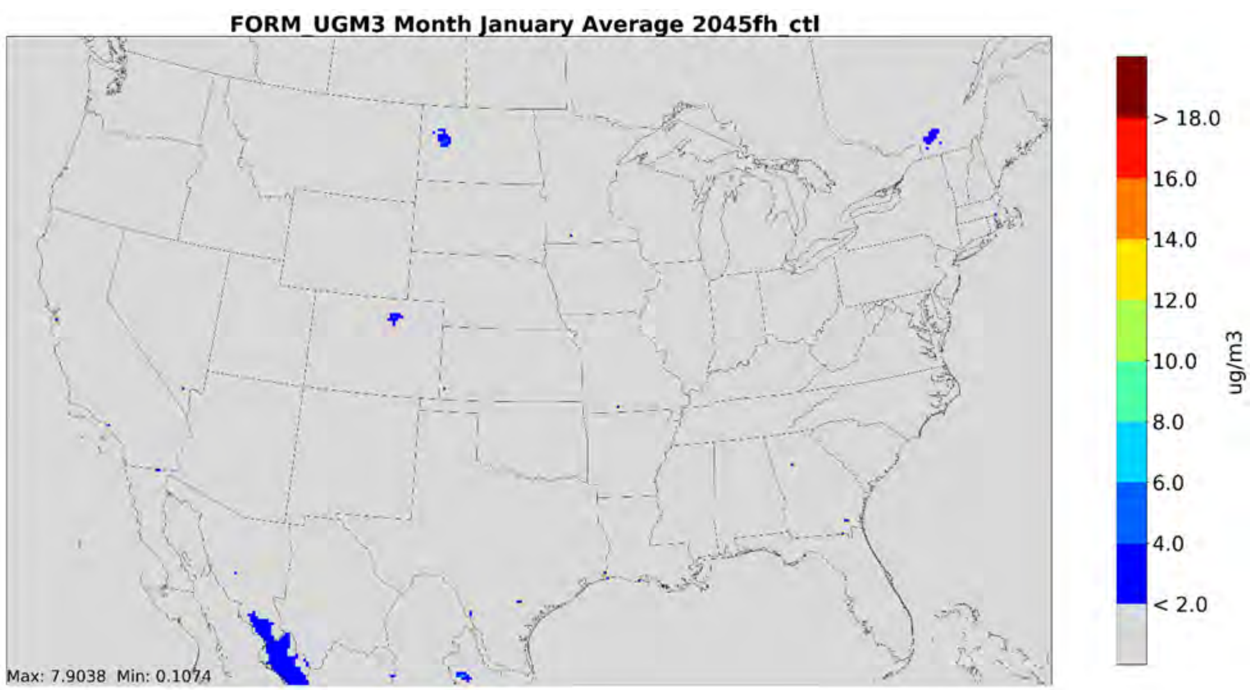

Figure 6-24 Projected January Average Formaldehyde Concentrations in 2045 with the Proposed Option 1 (ug/m^3)

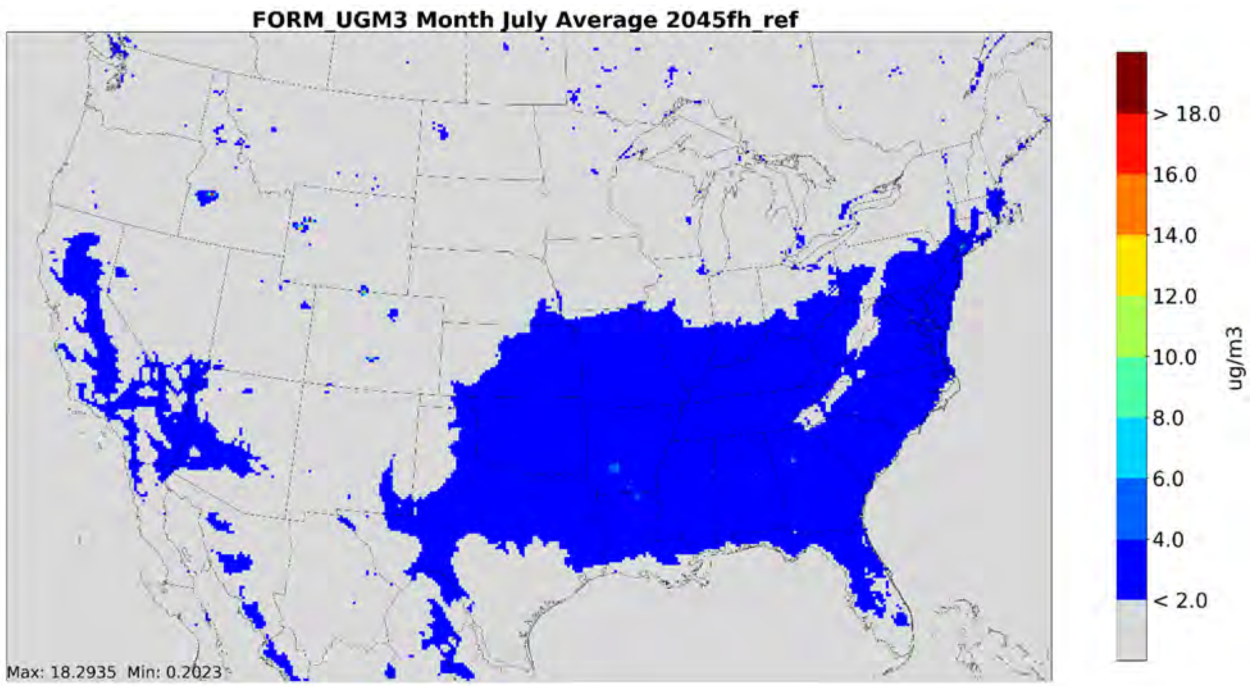

Figure 6-25 Projected July Average Formaldehyde Concentrations in 2045 without the Proposed Rule (ug/m^3)

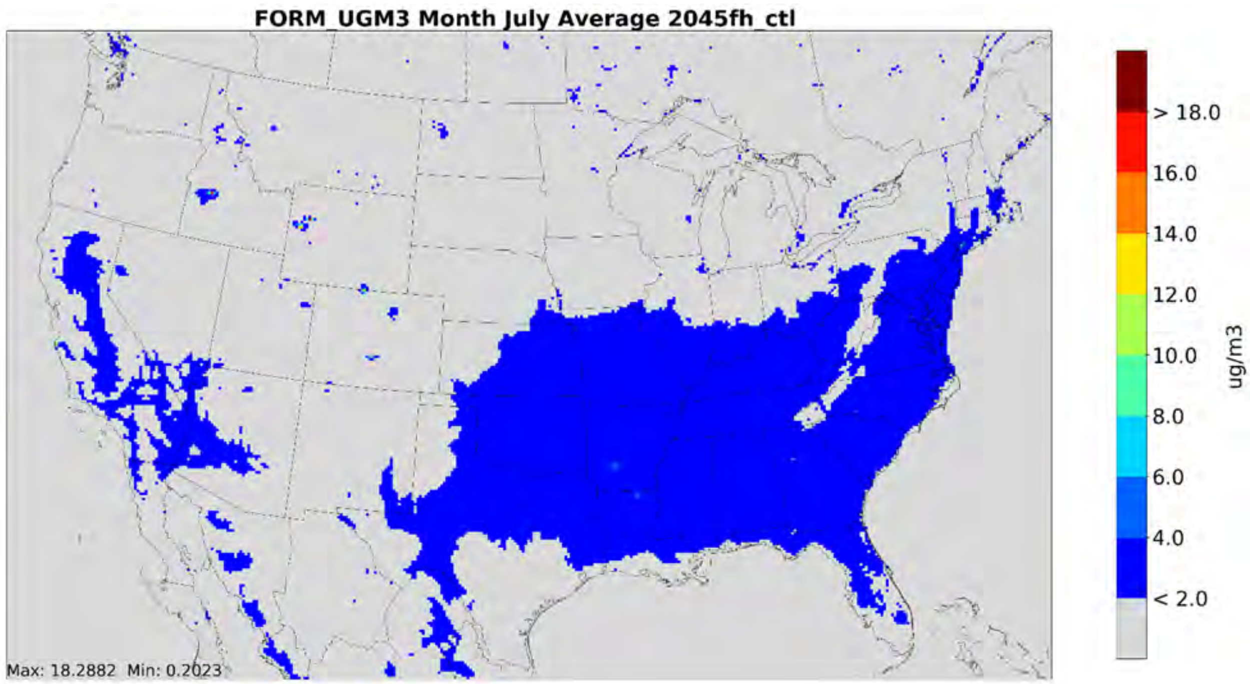

Figure 6-26 Projected July Average Formaldehyde Concentrations in 2045 with the Proposed Option 1 (ug/m^3)

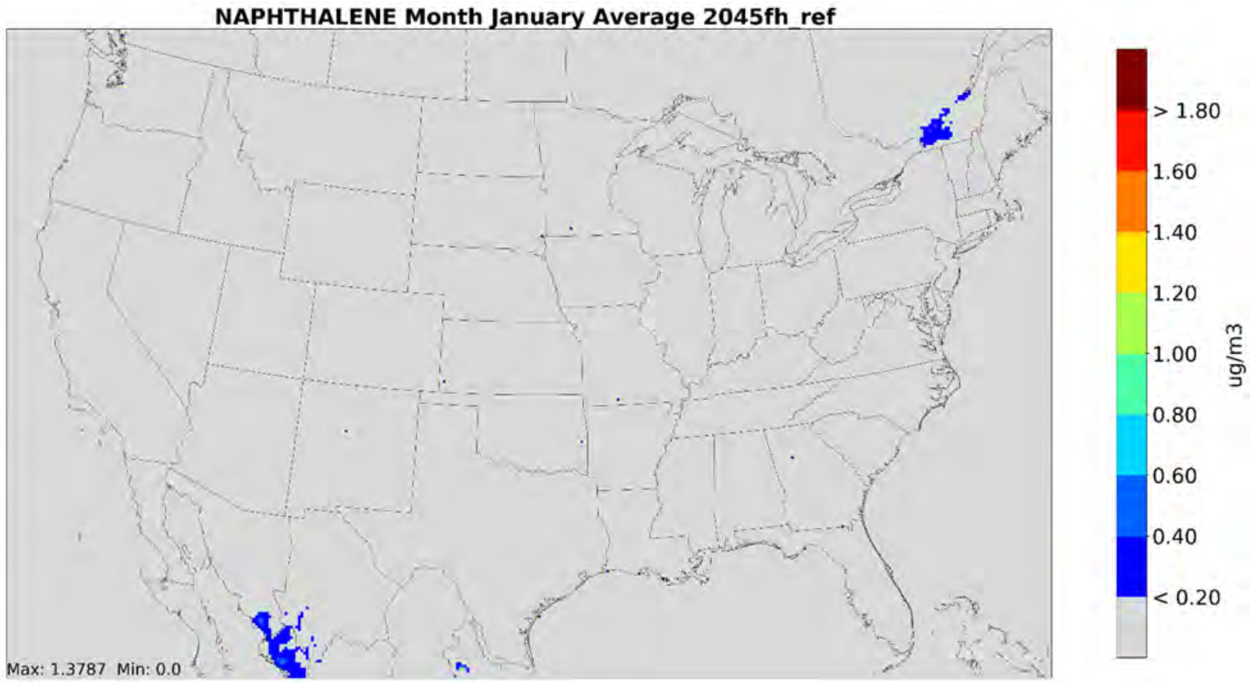

Figure 6-27 Projected January Average Naphthalene Concentrations in 2045 without the Proposed Rule (ug/m^3)

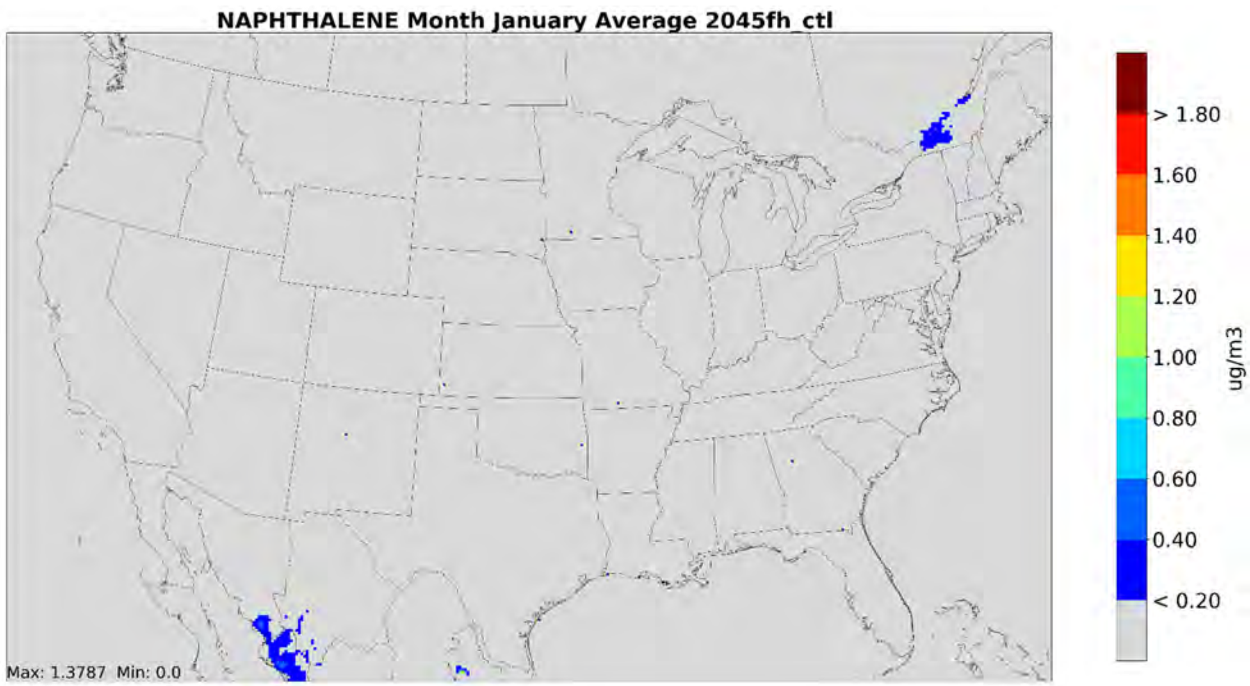

Figure 6-28 Projected January Average Naphthalene Concentrations in 2045 with the Proposed Option 1 (ug/m^3)

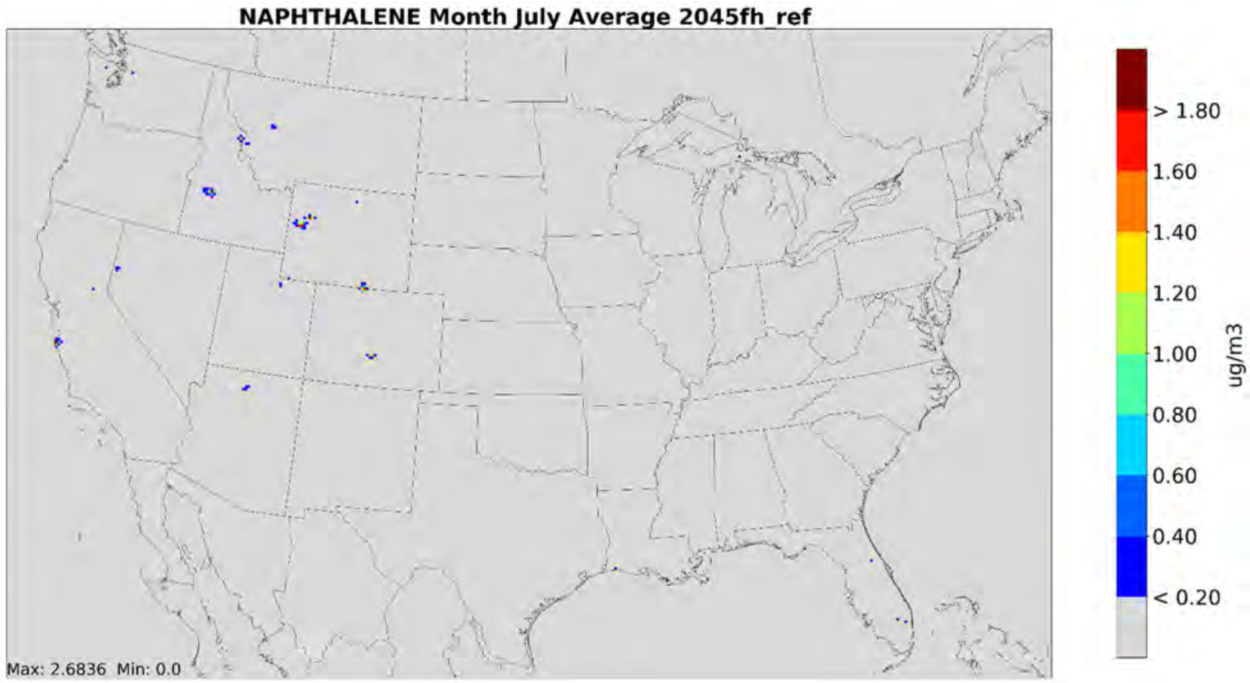

Figure 6-29 Projected July Average Naphthalene Concentrations in 2045 without the Proposed Rule (ug/m^3)

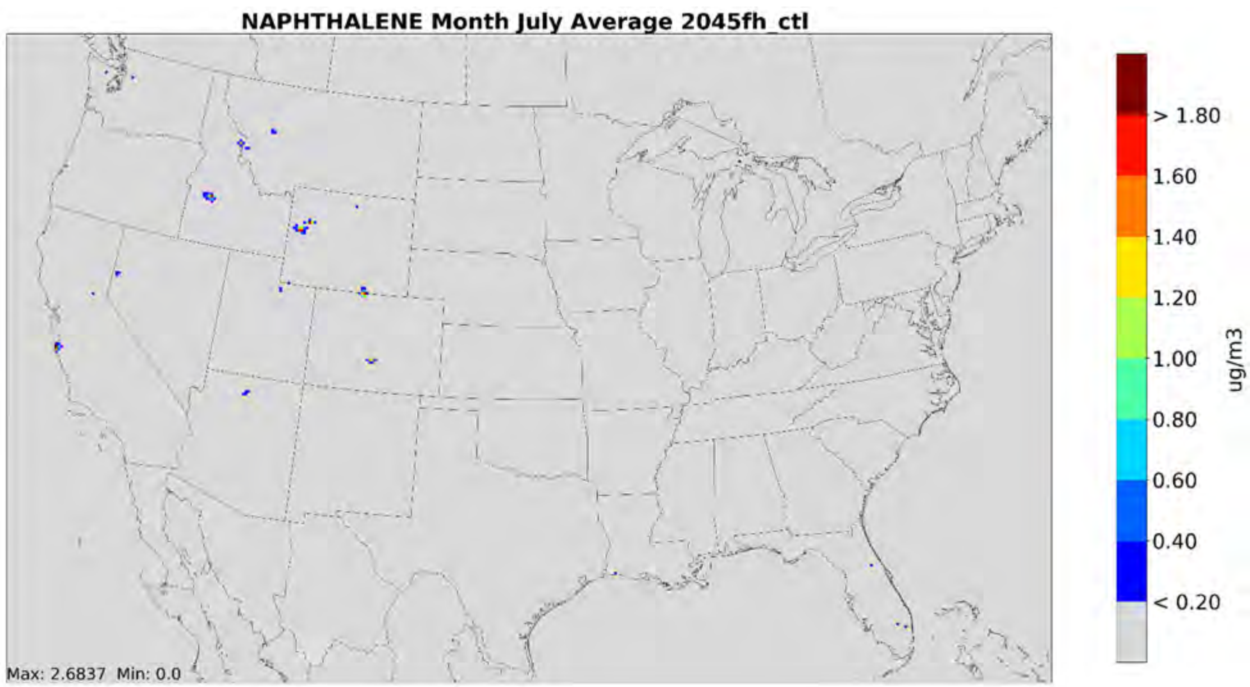

Figure 6-30 Projected July Average Naphthalene Concentrations in 2045 with the Proposed Option 1 (ug/m^3)

6.3 Seasonal Difference Maps

The following section presents maps of January and July monthly average changes (absolute change and percent change) in ambient concentrations of acetaldehyde, benzene, formaldehyde and naphthalene in 2045 due to the proposed rule.

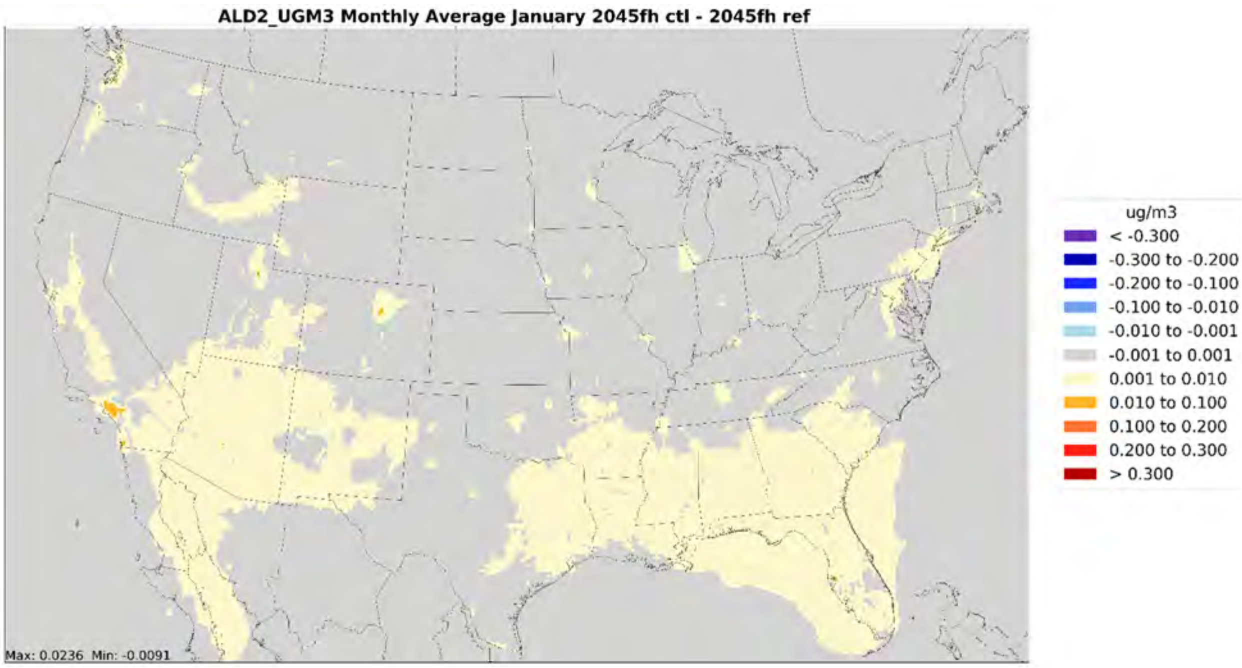

Figure 6-31 Changes in Ambient Acetaldehyde Concentrations (µg/m³) in January 2045 due to Proposed Rule

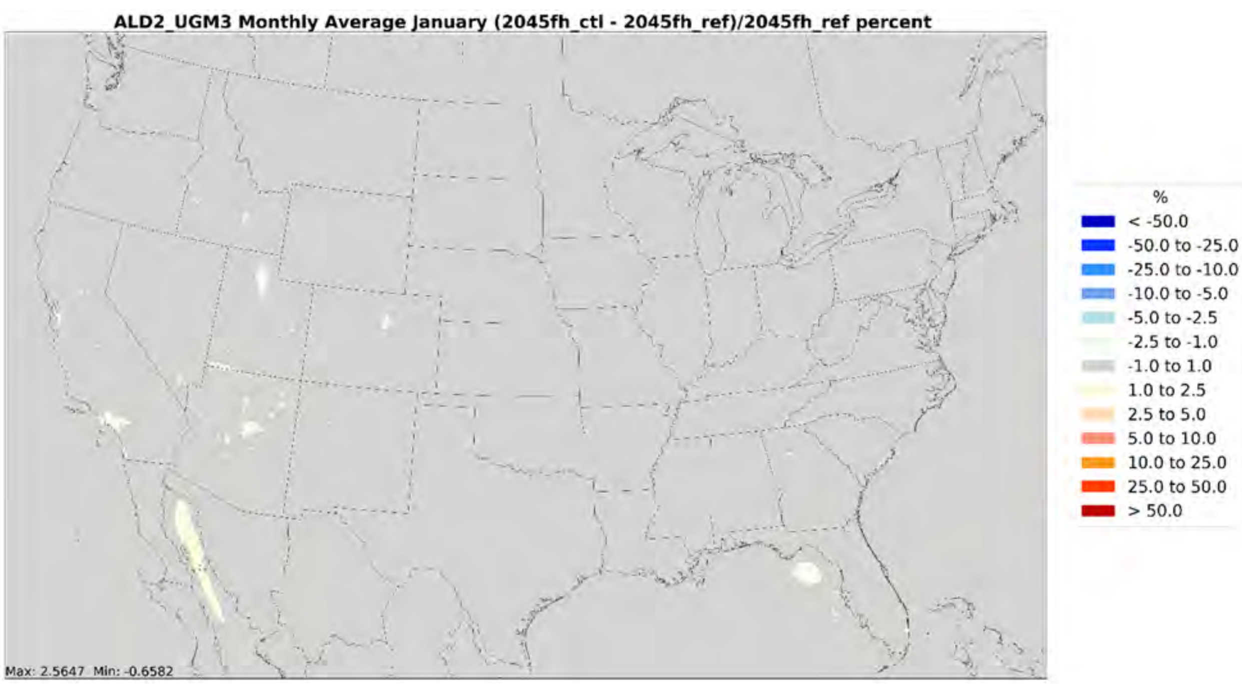

Figure 6-32 Percent Changes in Ambient Acetaldehyde Concentrations in January 2045 due to Proposed Rule

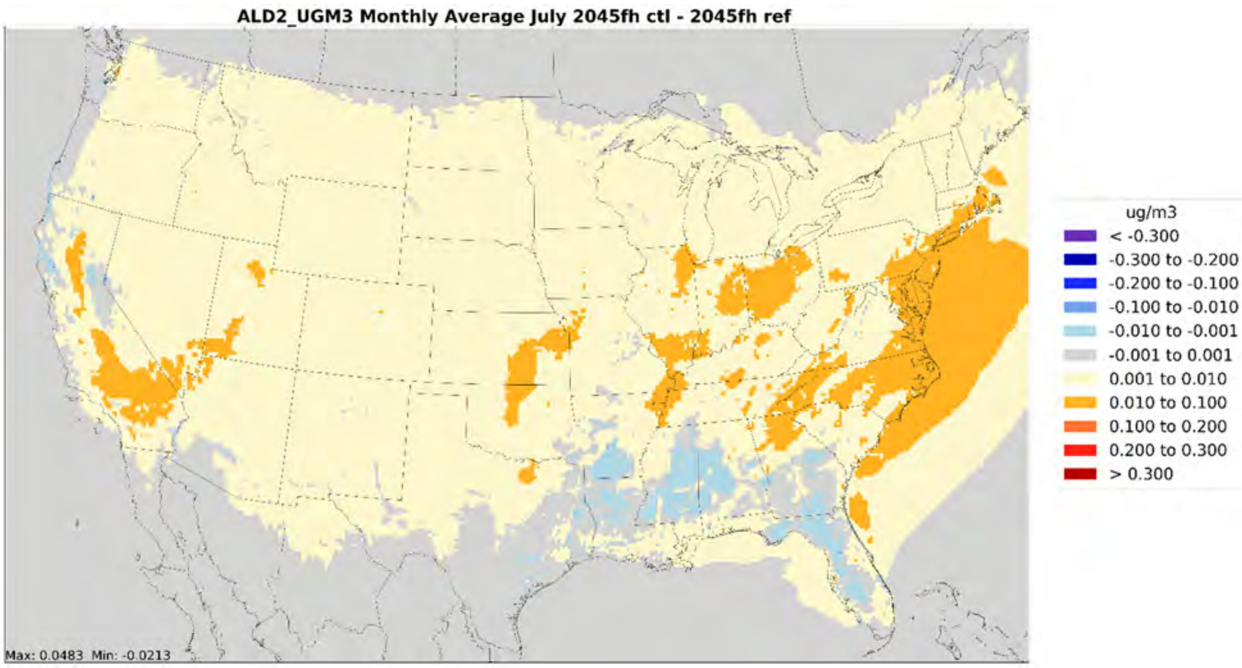

Figure 6-33 Changes in Ambient Acetaldehyde Concentrations (µg/m³) in July 2045 due to Proposed Rule

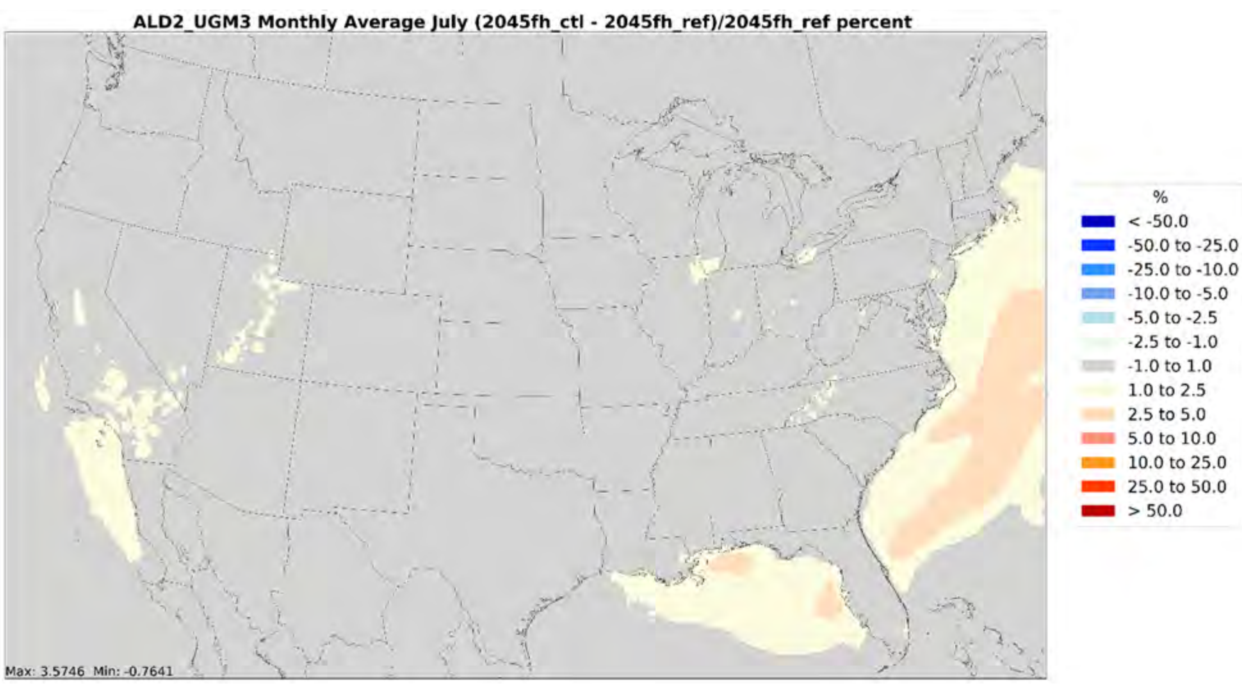

Figure 6-34 Percent Changes in Ambient Acetaldehyde Concentrations in July 2045 due to Proposed Rule

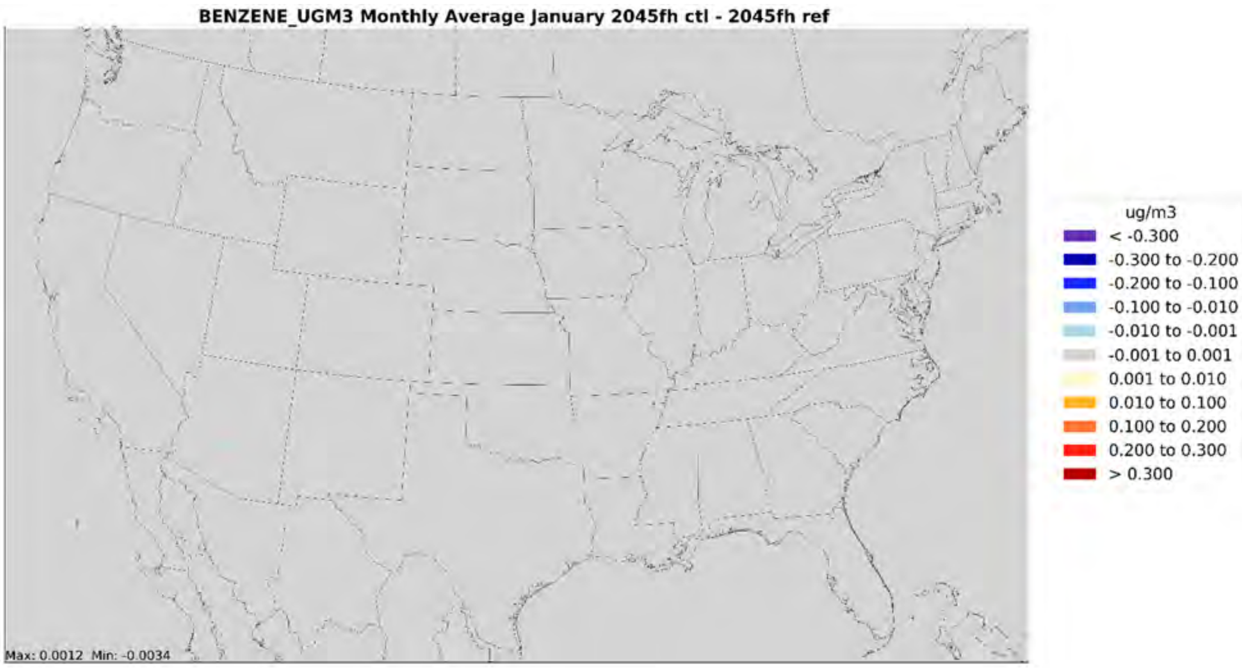

Figure 6-35 Changes in Ambient Benzene Concentrations (µg/m³) in January 2045 due to Proposed Rule

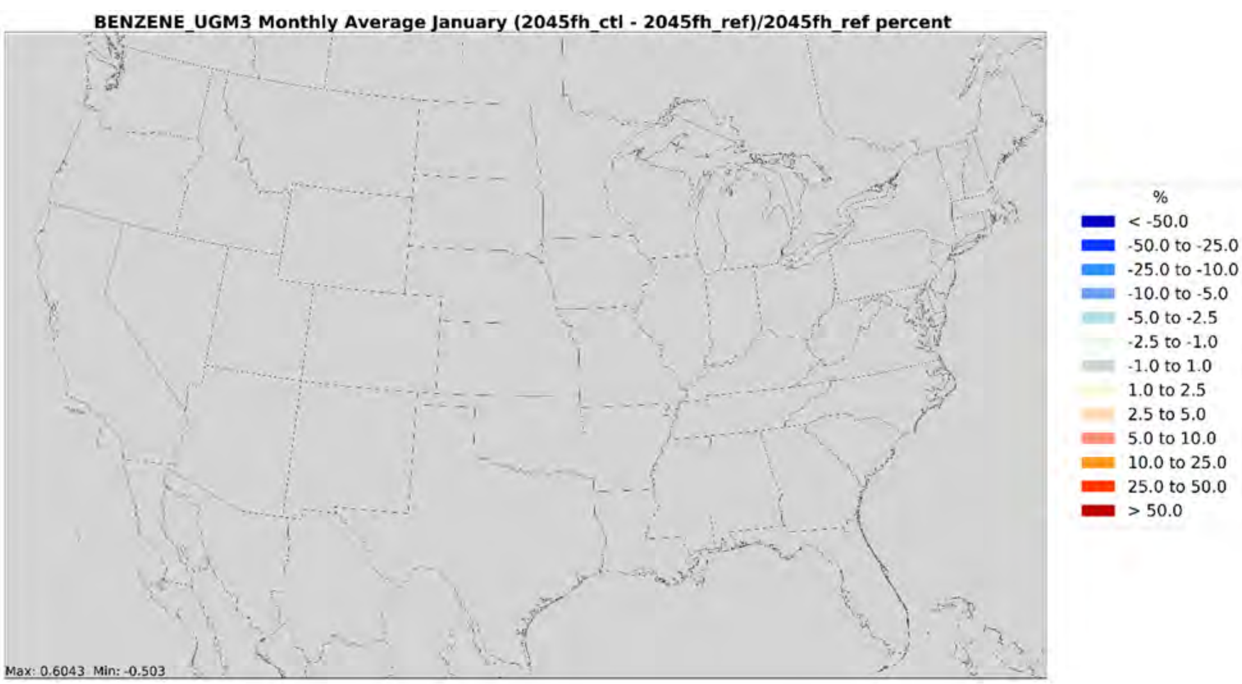

Figure 6-36 Percent Changes in Ambient Benzene Concentrations in January 2045 due to Proposed Rule

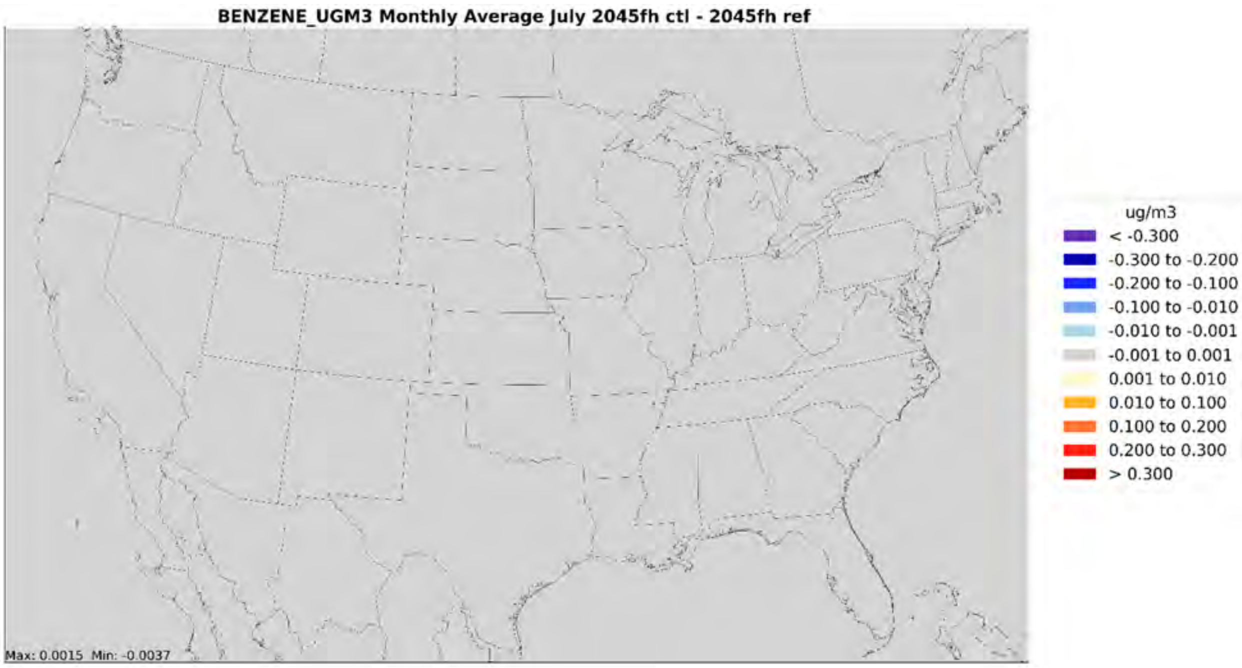

Figure 6-37 Changes in Ambient Benzene Concentrations (µg/m³) in July 2045 due to Proposed Rule

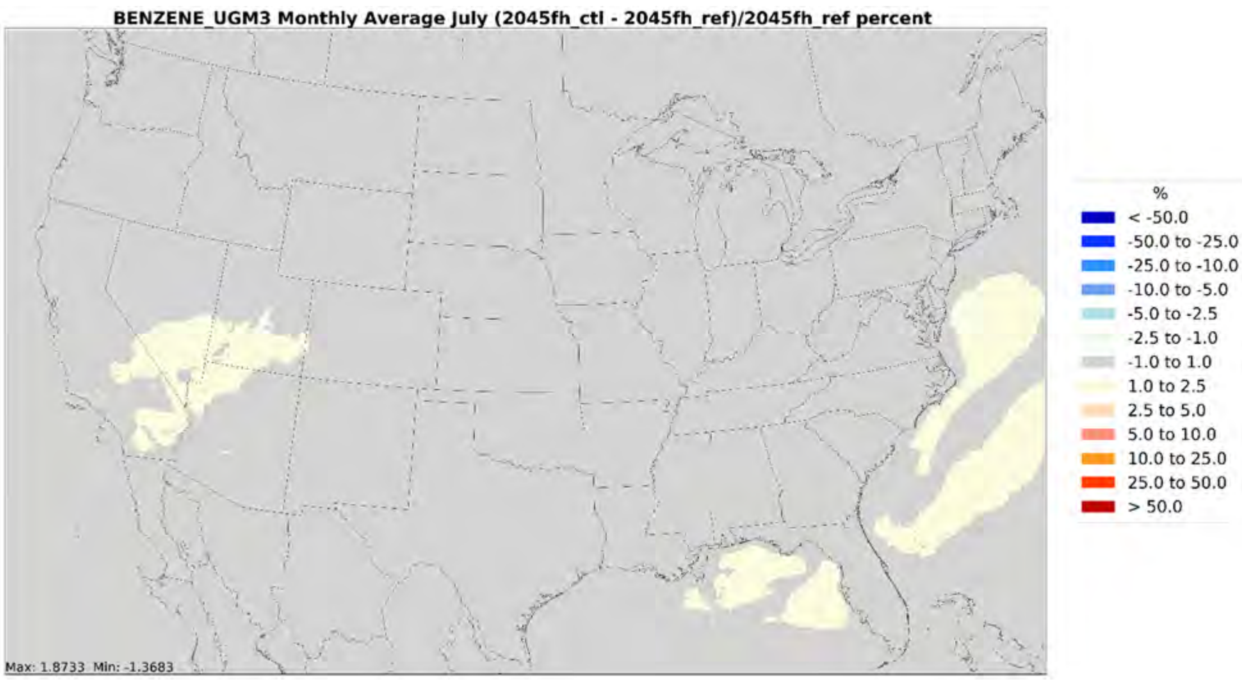

Figure 6-38 Percent Changes in Ambient Benzene Concentrations in July 2045 due to Proposed Rule

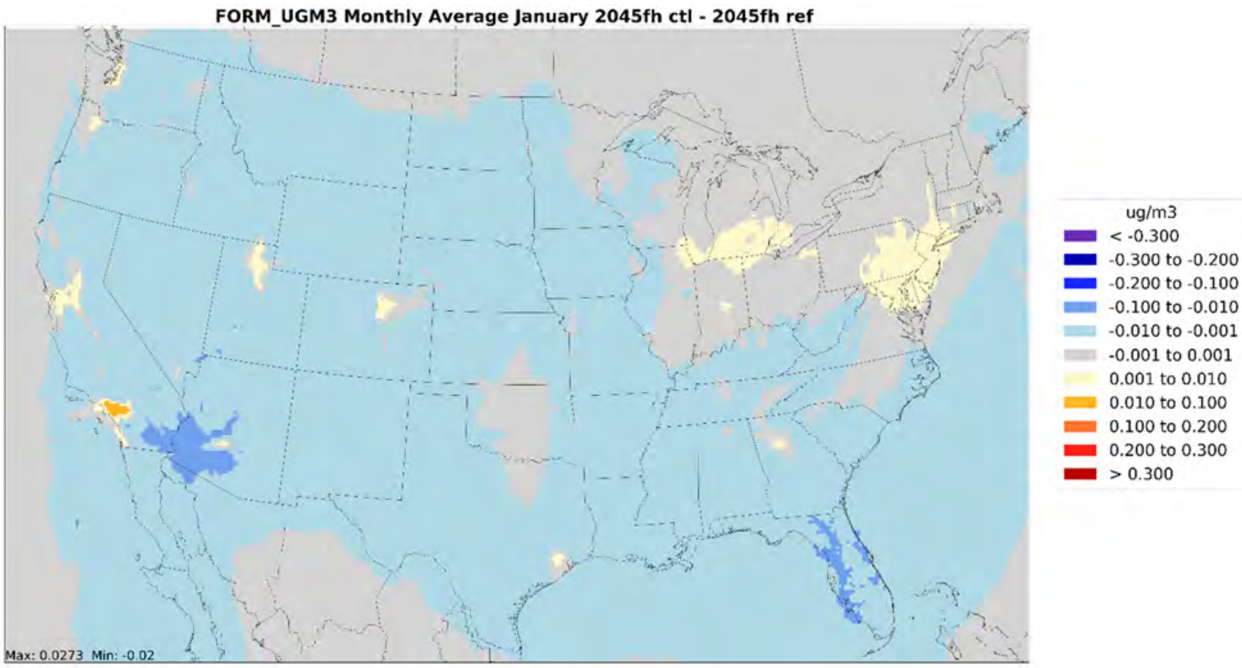

Figure 6-39 Changes in Ambient Formaldehyde Concentrations (µg/m³) in January 2045 due to Proposed Rule

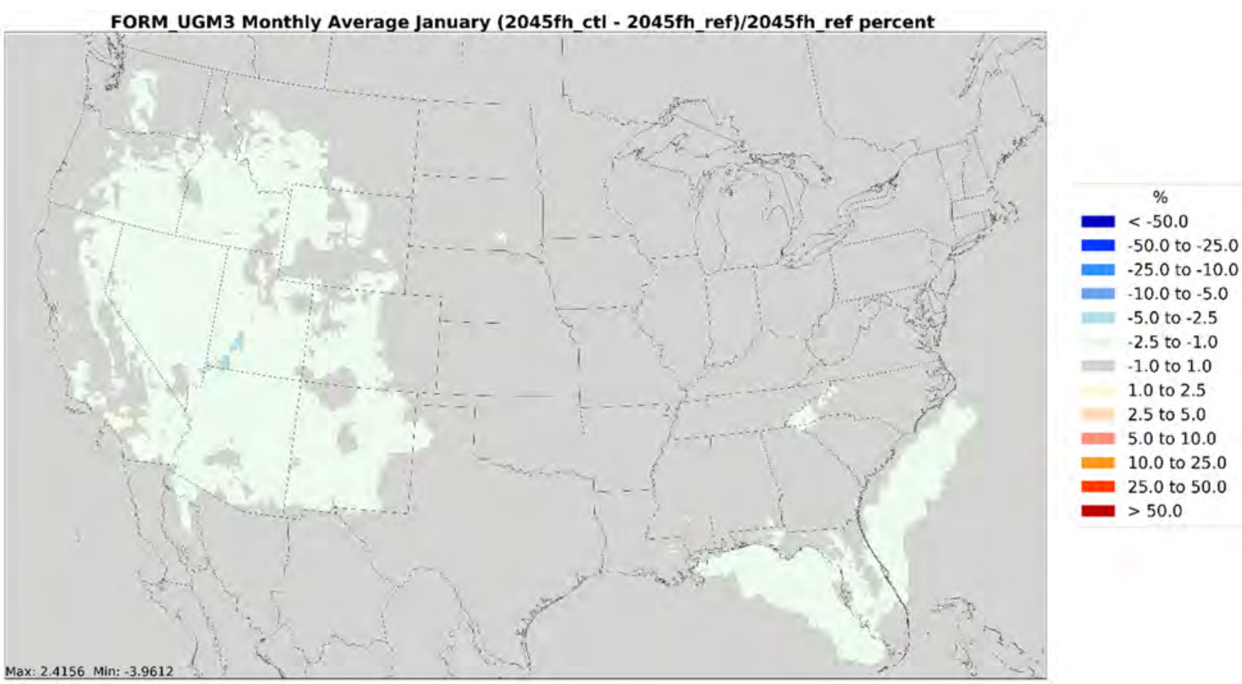

Figure 6-40 Percent Changes in Ambient Formaldehyde Concentrations in January 2045 due to Proposed Rule

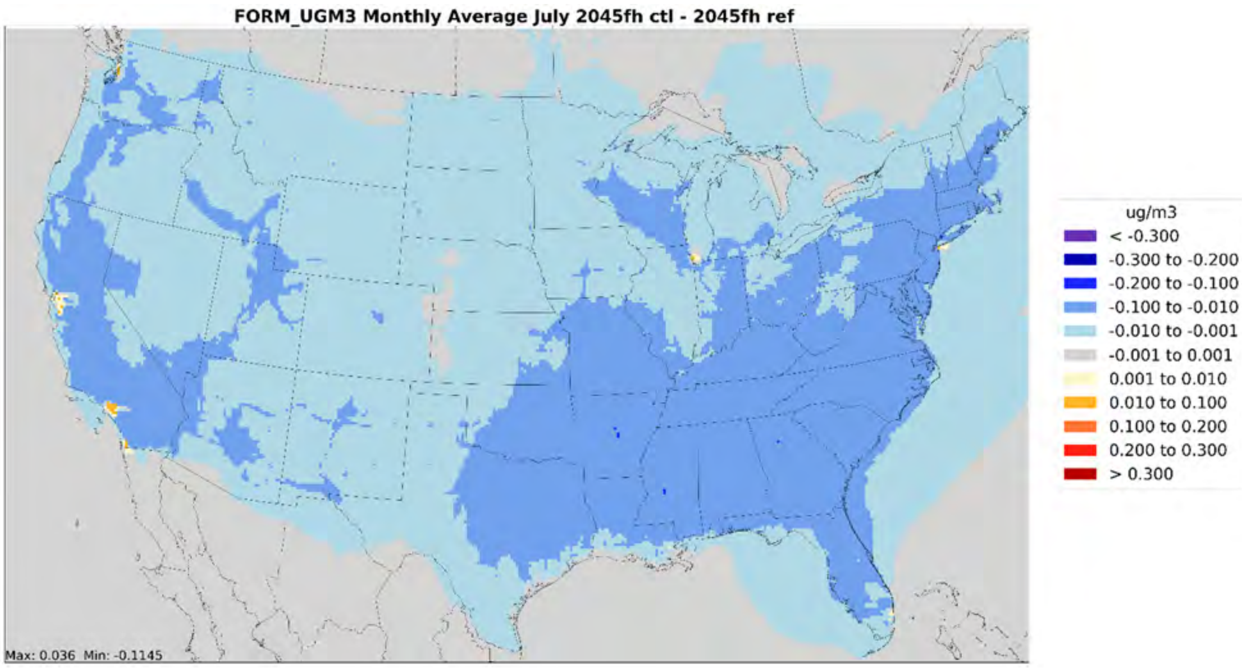

Figure 6-41 Changes in Ambient Formaldehyde Concentrations (µg/m³) in July 2045 due to Proposed Rule

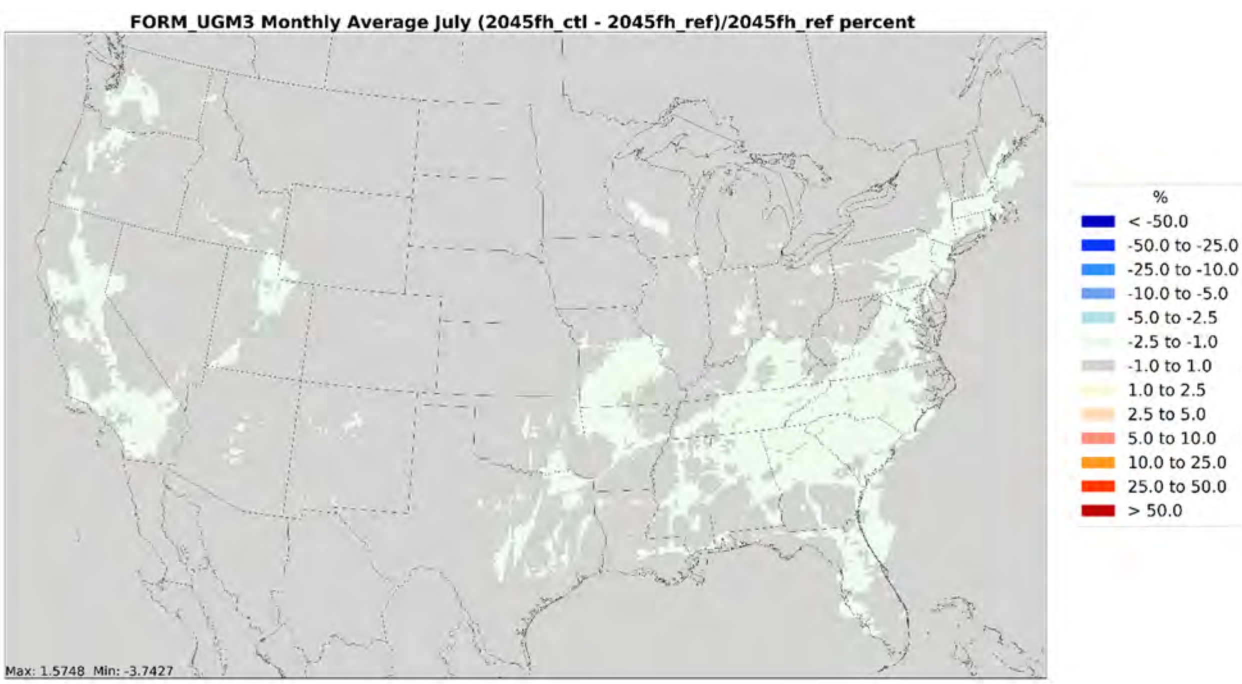

Figure 6-42 Percent Changes in Ambient Formaldehyde Concentrations in July 2045 due to Proposed Rule

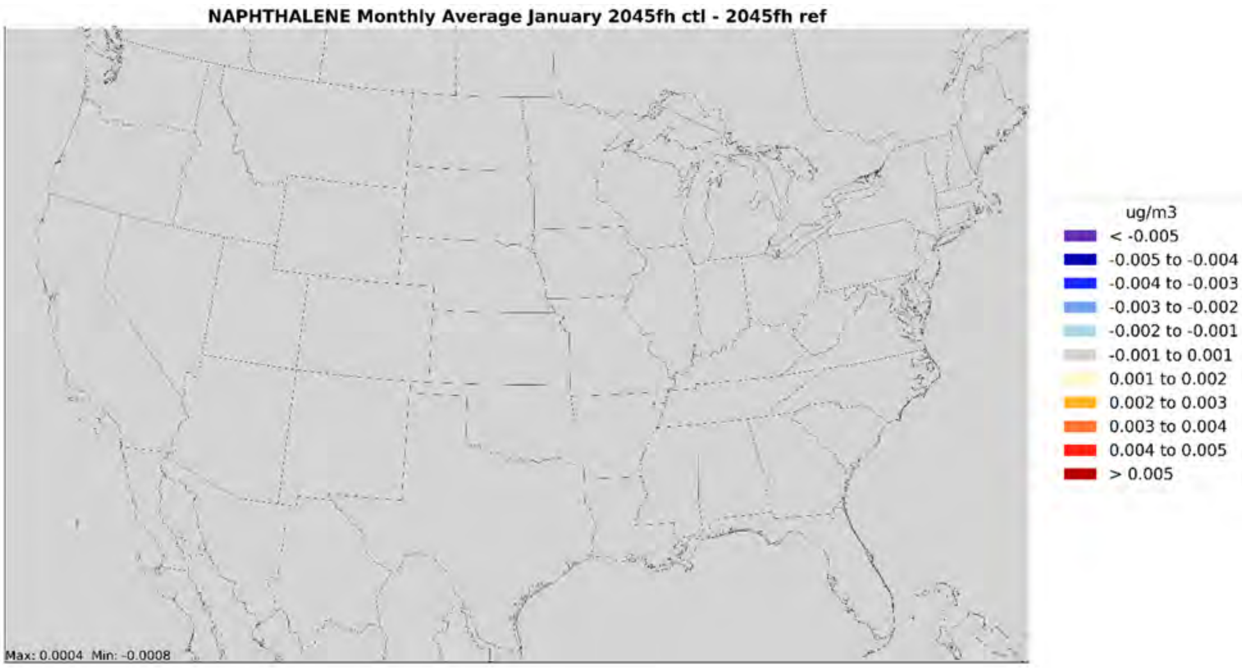

Figure 6-43 Changes in Ambient Naphthalene Concentrations (µg/m³) in January 2045 due to Proposed Rule

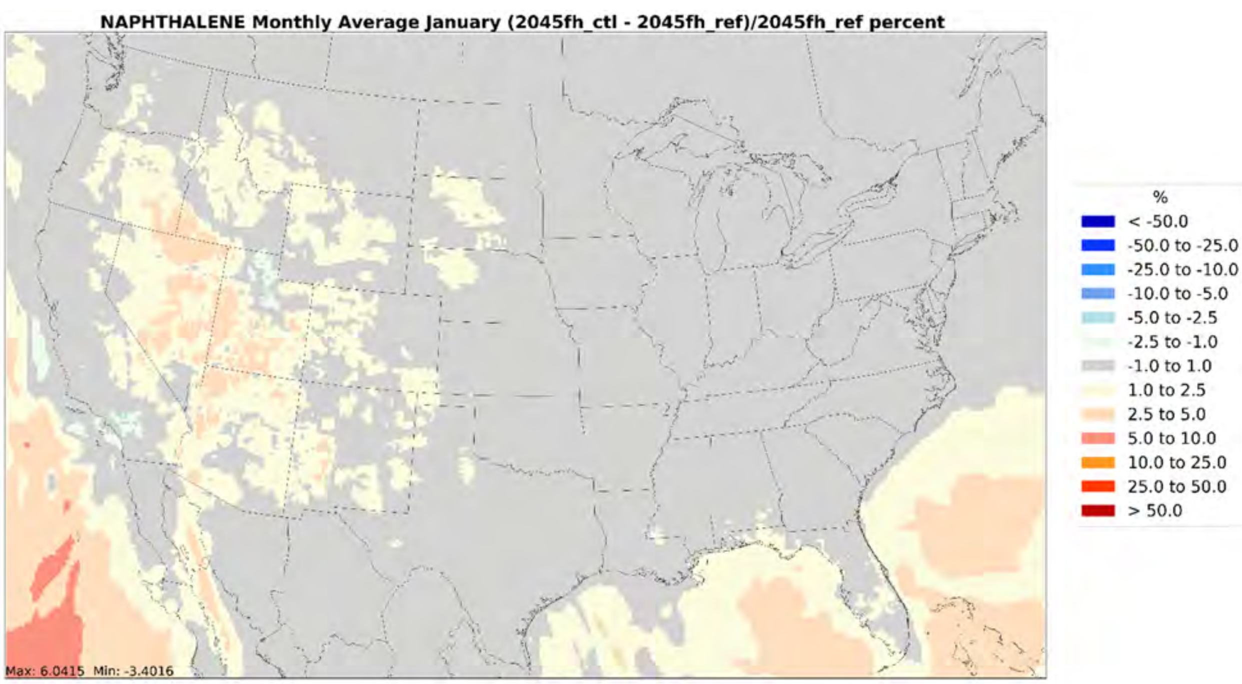

Figure 6-44 Percent Changes in Ambient Naphthalene Concentrations in January 2045 due to Proposed Rule

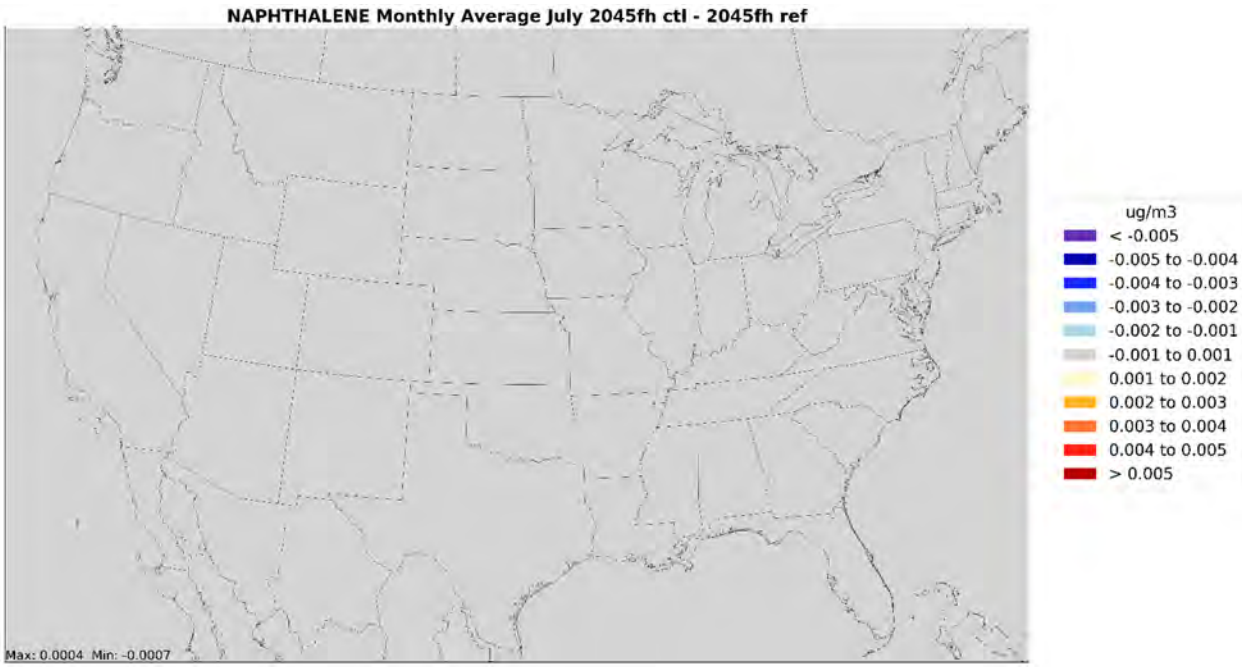

Figure 6-45 Changes in Ambient Naphthalene Concentrations (μg/m³) in July 2045 due to Proposed Rule

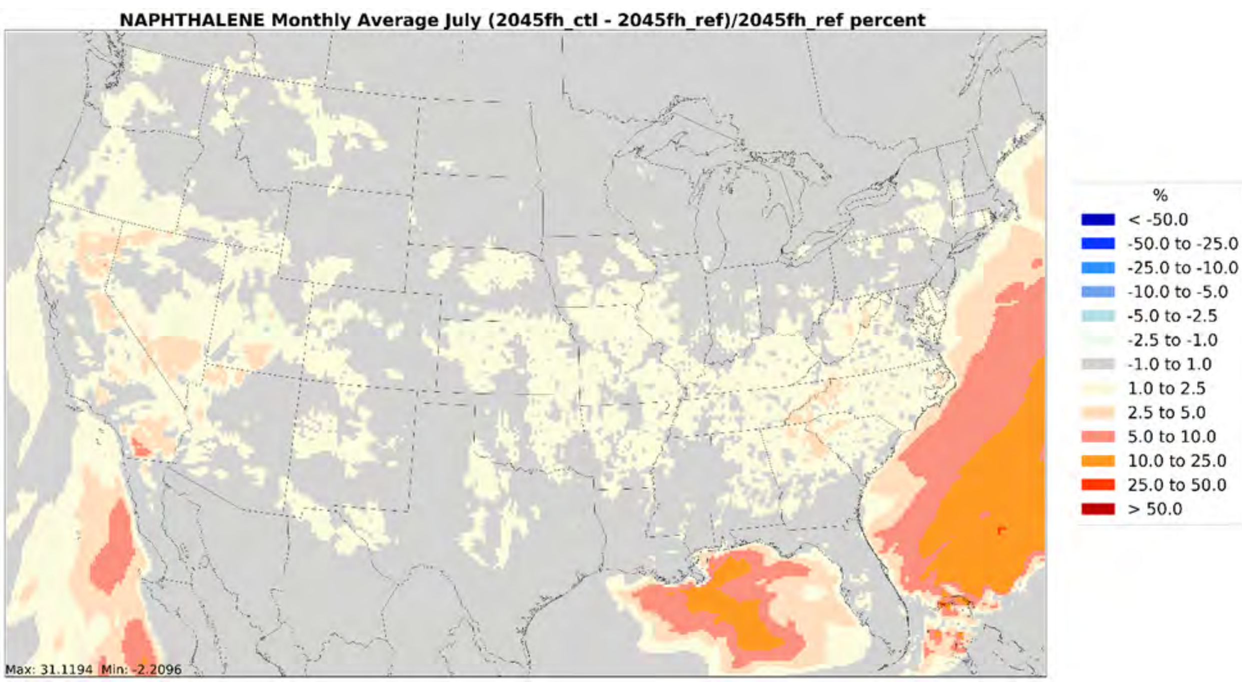

Figure 6-46 Percent Changes in Ambient Naphthalene Concentrations in July 2045 due to Proposed Rule

6.4 Visibility (dv) for Mandatory Class I Federal Areas

Class I Area Name	State	2016 Baseline Visibility (dv) on 20% Most Impaired Days	2045 Reference Visibility (dv) on 20% Most Impaired Days	2045 Control Visibility (dv) on 20% Most Impaired Days	Natural Background (dv) on 20% Most Impaired Days
Sipsey Wilderness	Alabama	19.03	17.27	17.12	9.62
Chiricahua NM	Arizona	9.41	8.85	8.84	4.93
Chiricahua Wilderness	Arizona	9.41	8.85	8.84	4.93
Galiuro Wilderness	Arizona	9.41	8.85	8.84	4.93
Grand Canyon NP	Arizona	6.87	6.56	6.55	4.16
Mazatzal Wilderness	Arizona	9.47	9.06	9.04	5.22
Mount Baldy Wilderness	Arizona	7.29	7.03	7.03	4.18
Petrified Forest NP	Arizona	8.16	7.69	7.67	4.21
Pine Mountain Wilderness	Arizona	9.47	9.06	9.04	5.22
Saguaro NM	Arizona	10.75	10.23	10.20	5.14
Superstition Wilderness	Arizona	10.45	9.95	9.93	5.14
Sycamore Canyon Wilderness	Arizona	11.63	11.29	11.27	4.68
Caney Creek Wilderness	Arkansas	18.29	16.37	16.27	9.54
Upper Buffalo Wilderness	Arkansas	17.95	16.33	16.22	9.41
Agua Tibia Wilderness	California	16.34	15.57	15.44	7.66
Ansel Adams Wilderness (Minarets)	California	10.98	10.44	10.38	6.06
Caribou Wilderness	California	10.23	9.80	9.76	6.10
Cucamonga Wilderness	California	13.19	12.55	12.38	6.12
Desolation Wilderness	California	9.31	8.91	8.87	4.91
Dome Land Wilderness	California	15.14	14.39	14.31	6.19
Emigrant Wilderness	California	11.57	11.20	11.16	6.29
Hoover Wilderness	California	7.65	7.37	7.35	4.90
John Muir Wilderness	California	10.98	10.44	10.38	6.06
Joshua Tree NM	California	12.87	12.39	12.30	6.09
Kaiser Wilderness	California	10.98	10.44	10.38	6.06
Kings Canyon NP	California	18.43	17.64	17.55	6.29
Lassen Volcanic NP	California	10.23	9.80	9.76	6.10
Lava Beds NM	California	9.67	9.37	9.34	6.18
Mokelumne Wilderness	California	9.31	8.91	8.87	4.91
Pinnacles NM	California	14.10	13.57	13.50	6.94
Redwood NP	California	12.65	12.44	12.43	8.59
San Gabriel Wilderness	California	13.19	12.55	12.38	6.12

Class I Area Name	State	2016 Baseline Visibility (dv) on 20% Most Impaired Days	2045 Reference Visibility (dv) on 20% Most Impaired Days	2045 Control Visibility (dv) on 20% Most Impaired Days	Natural Background (dv) on 20% Most Impaired Days
San Gorgonio Wilderness	California	14.45	13.45	13.24	6.20
San Jacinto Wilderness	California	14.45	13.45	13.24	6.20
San Rafael Wilderness	California	14.11	13.39	13.29	6.80
Sequoia NP	California	18.43	17.64	17.55	6.29
South Warner Wilderness	California	9.67	9.37	9.34	6.18
Thousand Lakes Wilderness	California	10.23	9.80	9.76	6.10
Ventana Wilderness	California	14.10	13.57	13.50	6.94
Yosemite NP	California	11.57	11.20	11.16	6.29
Black Canyon of the Gunnison NM	Colorado	6.55	6.36	6.35	3.97
Eagles Nest Wilderness	Colorado	4.98	4.75	4.73	3.02
Flat Tops Wilderness	Colorado	4.98	4.75	4.73	3.02
Great Sand Dunes NM	Colorado	8.02	7.73	7.72	4.45
La Garita Wilderness	Colorado	6.55	6.36	6.35	3.97
Maroon Bells-Snowmass Wilderness	Colorado	4.98	4.75	4.73	3.02
Mesa Verde NP	Colorado	6.51	6.16	6.14	4.20
Mount Zirkel Wilderness	Colorado	5.47	5.22	5.20	3.16
Rawah Wilderness	Colorado	5.47	5.22	5.20	3.16
Rocky Mountain NP	Colorado	8.41	7.92	7.88	4.94
Weminuche Wilderness	Colorado	6.55	6.36	6.35	3.97
West Elk Wilderness	Colorado	4.98	4.75	4.73	3.02
Chassahowitzka	Florida	17.41	16.19	16.14	9.03
Everglades NP	Florida	14.90	14.27	14.26	8.33
St. Marks	Florida	17.39	16.16	16.12	9.13
Cohutta Wilderness	Georgia	17.37	15.69	15.59	9.88
Okefenokee	Georgia	17.39	16.44	16.41	9.45
Wolf Island	Georgia	17.39	16.44	16.41	9.45
Craters of the Moon NM	Idaho	8.50	8.03	7.92	4.97
Sawtooth Wilderness	Idaho	8.61	8.36	8.34	4.70
Selway-Bitterroot Wilderness	Idaho	8.37	8.16	8.15	5.45
Mammoth Cave NP	Kentucky	21.02	19.17	19.04	9.80
Breton	Louisiana	19.04	18.19	18.16	9.23
Acadia NP	Maine	14.54	13.69	13.64	10.39
Moosehorn	Maine	13.32	12.68	12.65	9.98
Roosevelt Campobello International Park	Maine	13.32	12.68	12.65	9.98
Isle Royale NP	Michigan	15.54	14.96	14.89	10.17

Class I Area Name	State	2016 Baseline Visibility (dv) on 20% Most Impaired Days	2045 Reference Visibility (dv) on 20% Most Impaired Days	2045 Control Visibility (dv) on 20% Most Impaired Days	Natural Background (dv) on 20% Most Impaired Days
Seney	Michigan	17.57	16.58	16.48	11.11
Boundary Waters Canoe Area	Minnesota	13.96	13.28	13.22	9.09
Voyageurs NP	Minnesota	14.18	13.63	13.59	9.37
Hercules-Glades Wilderness	Missouri	18.72	17.13	17.01	9.30
Mingo	Missouri	20.13	18.67	18.56	9.18
Anaconda-Pintler Wilderness	Montana	8.37	8.16	8.15	5.45
Bob Marshall Wilderness	Montana	10.06	9.82	9.81	5.53
Cabinet Mountains Wilderness	Montana	9.87	9.63	9.61	5.64
Gates of the Mountains Wilderness	Montana	7.47	7.37	7.36	4.53
Glacier NP	Montana	13.77	13.42	13.39	6.90
Medicine Lake	Montana	15.30	15.38	15.36	5.95
Mission Mountains Wilderness	Montana	10.06	9.82	9.81	5.53
Red Rock Lakes	Montana	7.52	7.24	7.22	3.97
Scapegoat Wilderness	Montana	10.06	9.82	9.81	5.53
UL Bend	Montana	10.93	11.03	11.03	5.87
Jarbidge Wilderness	Nevada	7.97	7.82	7.81	5.23
Great Gulf Wilderness	New Hampshire	13.07	12.13	12.12	9.78
Presidential Range-Dry River Wilderness	New Hampshire	13.07	12.13	12.12	9.78
Brigantine	New Jersey	19.31	17.84	17.74	10.68
Bandelier NM	New Mexico	8.44	7.94	7.90	4.59
Bosque del Apache	New Mexico	10.47	10.07	10.04	5.39
Carlsbad Caverns NP	New Mexico	12.64	12.46	12.45	4.83
Gila Wilderness	New Mexico	7.58	7.26	7.25	4.20
Pecos Wilderness	New Mexico	5.95	5.59	5.57	3.50
Salt Creek	New Mexico	14.97	14.27	14.21	5.49
San Pedro Parks Wilderness	New Mexico	6.43	6.15	6.13	3.33
Wheeler Peak Wilderness	New Mexico	5.95	5.59	5.57	3.5
White Mountain Wilderness	New Mexico	9.95	9.71	9.70	4.89
Linville Gorge Wilderness	North Carolina	16.42	14.64	14.59	9.70
Shining Rock Wilderness	North Carolina	15.49	13.65	13.59	10.25
Swanquarter	North Carolina	16.30	15.01	14.94	10.01
Lostwood	North Dakota	16.18	16.13	16.10	5.87
Theodore Roosevelt NP	North Dakota	14.06	13.89	13.86	5.94
Wichita Mountains	Oklahoma	18.12	16.84	16.76	6.92
Crater Lake NP	Oregon	7.98	7.78	7.77	5.16

Class I Area Name	State	2016 Baseline Visibility (dv) on 20% Most Impaired Days	2045 Reference Visibility (dv) on 20% Most Impaired Days	2045 Control Visibility (dv) on 20% Most Impaired Days	Natural Background (dv) on 20% Most Impaired Days
Diamond Peak Wilderness	Oregon	7.98	7.78	7.77	5.16
Eagle Cap Wilderness	Oregon	11.19	10.54	10.43	6.58
Gearhart Mountain Wilderness	Oregon	7.98	7.78	7.77	5.16
Hells Canyon Wilderness	Oregon	12.33	11.91	11.82	6.57
Kalmiopsis Wilderness	Oregon	11.97	11.68	11.66	7.78
Mount Hood Wilderness	Oregon	9.27	8.99	8.96	6.59
Mount Jefferson Wilderness	Oregon	11.28	11.00	10.98	7.30
Mount Washington Wilderness	Oregon	11.28	11.00	10.98	7.30
Mountain Lakes Wilderness	Oregon	7.98	7.78	7.77	5.16
Strawberry Mountain Wilderness	Oregon	11.19	10.54	10.43	6.58
Three Sisters Wilderness	Oregon	11.28	11.00	10.98	7.30
Cape Romain	South Carolina	17.67	16.52	16.47	9.78
Badlands NP	South Dakota	12.33	12.01	11.98	6.09
Wind Cave NP	South Dakota	10.53	10.13	10.11	5.64
Great Smoky Mountains NP	Tennessee	17.21	15.45	15.37	10.05
Joyce-Kilmer-Slickrock Wilderness	Tennessee	17.21	15.45	15.37	10.05
Big Bend NP	Texas	14.06	13.87	13.86	5.33
Guadalupe Mountains NP	Texas	12.64	12.46	12.45	4.83
Arches NP	Utah	6.76	6.30	6.27	4.13
Bryce Canyon NP	Utah	6.60	6.30	6.27	4.08
Canyonlands NP	Utah	6.76	6.30	6.27	4.13
Capitol Reef NP	Utah	7.18	6.88	6.86	4.00
Zion NP	Utah	8.76	8.49	8.47	5.18
Lye Brook Wilderness	Vermont	14.73	13.73	13.66	10.24
James River Face Wilderness	Virginia	17.89	16.02	15.94	9.47
Shenandoah NP	Virginia	17.07	15.17	15.05	9.52
Alpine Lake Wilderness	Washington	12.74	12.15	12.08	7.27
Glacier Peak Wilderness	Washington	9.98	9.69	9.67	6.89
Goat Rocks Wilderness	Washington	7.98	7.75	7.73	6.14
Mount Adams Wilderness	Washington	7.98	7.75	7.73	6.14
Mount Rainier NP	Washington	12.66	12.24	12.22	7.66
North Cascades NP	Washington	9.98	9.69	9.67	6.89
Olympic NP	Washington	11.90	11.76	11.75	6.90
Pasayten Wilderness	Washington	9.46	9.16	9.14	5.96
Dolly Sods Wilderness	West Virginia	17.65	16.01	15.96	8.92

Class I Area Name	State	2016 Baseline Visibility (dv) on 20% Most Impaired Days	2045 Reference Visibility (dv) on 20% Most Impaired Days	2045 Control Visibility (dv) on 20% Most Impaired Days	Natural Background (dv) on 20% Most Impaired Days
Otter Creek Wilderness	West Virginia	17.65	16.01	15.96	8.92
Bridger Wilderness	Wyoming	6.77	6.50	6.48	3.92
Fitzpatrick Wilderness	Wyoming	6.77	6.50	6.48	3.92
Grand Teton NP	Wyoming	7.52	7.24	7.22	3.97
North Absaroka Wilderness	Wyoming	7.17	6.92	6.90	4.55
Teton Wilderness	Wyoming	7.52	7.24	7.22	3.97
Washakie Wilderness	Wyoming	7.17	6.92	6.90	4.55
Yellowstone NP	Wyoming	7.52	7.24	7.22	3.97

[a] The level of visibility impairment in an area is based on the light-extinction coefficient and a unitless visibility index, called a “deciview”, which is used in the valuation of visibility. The deciview metric provides a scale for perceived visual changes over the entire range of conditions, from clear to hazy. Under many scenic conditions, the average person can generally perceive a change of one deciview. The higher the deciview value, the worse the visibility. Thus, an improvement in visibility is a decrease in deciview value.

6.5 Ozone and $PM_{2.5}$ Design Values

Table 6-1 Modeled Ozone Design Values

State	County	2016 O_3 Design Value (ppb)	2045 ref O_3 Design Value (ppb)	2045 ctl O_3 Design Value (ppb)
Alabama	Baldwin	63.7	49.3	47.5
Alabama	Jefferson	67.7	51.7	48.9
Alabama	Madison	64.0	48.0	45.3
Alabama	Mobile	63.7	51.6	49.9
Alabama	Montgomery	61.0	45.7	42.9
Alabama	Morgan	63.7	51.9	49.9
Alabama	Russell	62.0	46.3	43.5
Alabama	Shelby	66.7	49.5	46.4
Alabama	Tuscaloosa	60.0	46.0	43.6
Arizona	Coconino	66.7	61.7	61.3
Arizona	Gila	72.3	61.6	60.1
Arizona	Maricopa	76.0	60.7	58.8
Arizona	Pima	69.3	61.7	61.1
Arizona	Pinal	72.7	59.3	57.6
Arizona	Yuma	72.3	69.4	68.9
Arkansas	Crittenden	67.0	56.7	54.8
Arkansas	Pulaski	63.7	48.0	45.1
California	Alameda	74.0	67.0	64.8
California	Amador	72.3	60.0	57.6

State	County	2016 O_3 Design Value (ppb)	2045 ref O_3 Design Value (ppb)	2045 ctl O_3 Design Value (ppb)
California	Butte	76.7	62.5	60.1
California	Calaveras	77.0	64.8	62.5
California	Colusa	62.7	52.3	50.6
California	Contra Costa	67.7	60.8	58.6
California	El Dorado	85.3	68.2	64.5
California	Fresno	91.0	74.9	72.1
California	Glenn	63.5	52.4	50.7
California	Imperial	76.7	76.6	76.3
California	Inyo	71.5	68.1	67.6
California	Kern	89.3	76.5	74.3
California	Kings	83.3	68.9	66.6
California	Lake	57.0	45.9	44.8
California	Los Angeles	100.0	92.3	89.0
California	Madera	82.7	68.8	66.5
California	Mariposa	76.0	72.0	71.4
California	Merced	80.7	67.7	65.3
California	Monterey	58.3	54.5	54.0
California	Nevada	86.3	70.5	67.3
California	Orange	77.7	66.6	63.2
California	Placer	85.0	69.6	66.2
California	Riverside	99.7	83.3	78.2
California	Sacramento	82.3	67.3	63.6
California	San Benito	68.3	62.0	61.2
California	San Bernardino	110.3	98.0	93.4
California	San Diego	83.0	75.2	72.7
California	San Joaquin	77.3	66.1	63.2
California	San Luis Obispo	72.3	64.0	62.7
California	Santa Clara	68.7	61.3	59.3
California	Santa Cruz	56.0	51.0	49.8
California	Shasta	76.0	61.8	59.6
California	Solano	66.3	55.9	53.2
California	Stanislaus	83.7	70.9	68.2
California	Sutter	73.0	63.7	61.8
California	Tehama	79.7	64.9	62.6
California	Tulare	89.0	71.5	69.1
California	Tuolumne	80.7	69.1	66.9
California	Ventura	77.3	63.4	60.3
California	Yolo	68.7	57.3	54.5
Colorado	Adams	67.0	59.7	58.4
Colorado	Arapahoe	73.0	64.3	62.9
Colorado	Denver	68.7	61.2	59.9
Colorado	Douglas	77.3	66.8	65.4
Colorado	El Paso	68.0	61.4	60.7
Colorado	Jefferson	79.3	70.3	68.8
Colorado	La Plata	68.7	65.6	65.3
Colorado	Larimer	75.7	68.0	67.2
Colorado	Weld	70.0	64.6	64.1
Connecticut	Fairfield	82.7	79.4	78.0

State	County	2016 O_3 Design Value (ppb)	2045 ref O_3 Design Value (ppb)	2045 ctl O_3 Design Value (ppb)
Connecticut	Hartford	71.7	60.0	58.2
Connecticut	Litchfield	71.3	60.6	58.6
Connecticut	Middlesex	78.7	66.5	64.4
Connecticut	New Haven	79.7	68.0	66.6
Connecticut	New London	74.3	64.9	64.0
Connecticut	Tolland	71.7	59.1	57.2
Connecticut	Windham	69.7	58.1	56.3
Delaware	Kent	66.3	55.5	54.7
Delaware	New Castle	73.7	62.0	60.0
Delaware	Sussex	67.7	51.6	50.8
District of Columbia	District of Columbia	71.0	57.0	54.1
Florida	Duval	61.0	46.7	44.8
Florida	Escambia	64.0	49.8	47.7
Florida	Hillsborough	67.7	55.8	53.8
Florida	Lake	63.7	52.6	51.3
Florida	Manatee	63.0	49.8	47.6
Florida	Okaloosa	61.0	46.7	44.9
Florida	Orange	63.0	50.9	48.7
Florida	Osceola	64.3	49.4	46.6
Florida	Pasco	62.0	50.1	48.0
Florida	Pinellas	62.7	51.3	49.2
Florida	Santa Rosa	62.0	47.4	45.4
Florida	Seminole	62.7	49.2	46.8
Georgia	Bibb	65.0	46.0	43.3
Georgia	Clarke	64.3	49.8	47.1
Georgia	Cobb	66.5	50.6	46.2
Georgia	Columbia	60.0	46.9	44.5
Georgia	Coweta	64.5	50.8	47.6
Georgia	Dawson	65.0	48.3	44.9
Georgia	DeKalb	70.3	56.4	52.8
Georgia	Douglas	68.0	54.1	50.7
Georgia	Fulton	74.3	60.2	56.6
Georgia	Gwinnett	70.7	52.9	48.7
Georgia	Henry	72.0	57.2	53.9
Georgia	Muscogee	61.0	45.6	42.9
Georgia	Paulding	63.0	53.3	50.8
Georgia	Pike	67.5	54.4	51.5
Georgia	Richmond	61.7	48.1	45.5
Georgia	Rockdale	71.0	57.1	53.8
Idaho	Ada	69.7	59.8	58.0
Idaho	Butte	61.0	59.6	59.4
Illinois	Champaign	65.7	54.4	52.7
Illinois	Cook	74.0	67.9	66.7
Illinois	DuPage	69.7	61.2	58.6
Illinois	Jersey	69.0	59.8	57.2
Illinois	Kane	69.3	59.6	57.1
Illinois	Lake	73.7	67.4	65.8
Illinois	Madison	70.7	61.3	58.2

State	County	2016 O_3 Design Value (ppb)	2045 ref O_3 Design Value (ppb)	2045 ctl O_3 Design Value (ppb)
Illinois	McHenry	69.7	59.8	57.4
Illinois	Randolph	66.3	57.6	55.5
Illinois	Saint Clair	69.0	58.4	54.6
Indiana	Allen	64.7	53.2	51.1
Indiana	Boone	67.0	55.2	52.6
Indiana	Carroll	63.7	53.0	50.9
Indiana	Clark	70.3	56.2	53.8
Indiana	Delaware	62.3	50.6	48.9
Indiana	Elkhart	64.3	53.6	51.8
Indiana	Floyd	71.0	59.1	56.9
Indiana	Greene	66.7	50.0	48.9
Indiana	Hamilton	66.3	52.8	49.8
Indiana	Hendricks	63.3	53.1	50.7
Indiana	Huntington	60.7	49.4	47.4
Indiana	Jackson	65.7	52.9	51.5
Indiana	Johnson	61.0	49.3	47.0
Indiana	Knox	66.7	48.9	47.9
Indiana	Lake	68.3	61.4	60.1
Indiana	LaPorte	65.0	58.3	57.0
Indiana	Madison	62.3	49.7	47.2
Indiana	Marion	70.3	56.3	52.9
Indiana	Morgan	63.0	53.2	51.4
Indiana	Perry	66.7	53.2	52.1
Indiana	Porter	69.7	62.0	60.4
Indiana	Posey	66.7	53.5	52.2
Indiana	Shelby	64.7	51.9	49.0
Indiana	St. Joseph	70.0	59.1	57.1
Indiana	Vanderburgh	69.0	56.2	55.2
Indiana	Vigo	66.7	52.5	50.7
Indiana	Warrick	68.7	55.3	54.5
Kansas	Johnson	60.0	50.7	48.4
Kansas	Leavenworth	61.3	50.7	48.5
Kansas	Wyandotte	63.0	53.4	50.9
Kentucky	Boone	63.0	49.5	48.1
Kentucky	Boyd	65.0	57.8	56.8
Kentucky	Bullitt	65.7	51.8	50.1
Kentucky	Campbell	68.7	59.0	56.4
Kentucky	Daviess	65.0	48.3	47.4
Kentucky	Fayette	65.7	52.6	50.1
Kentucky	Greenup	61.7	53.7	52.6
Kentucky	Hancock	67.5	48.9	47.9
Kentucky	Hardin	64.7	51.0	49.3
Kentucky	Henderson	68.3	55.4	54.6
Kentucky	Jefferson	74.3	61.8	59.4
Kentucky	Jessamine	64.0	48.4	46.7
Kentucky	Livingston	65.0	55.0	54.0
Kentucky	McCracken	62.7	53.5	52.8
Kentucky	Oldham	68.3	54.2	52.2

State	County	2016 O_3 Design Value (ppb)	2045 ref O_3 Design Value (ppb)	2045 ctl O_3 Design Value (ppb)
Louisiana	Ascension	70.0	59.6	57.5
Louisiana	Bossier	65.3	53.8	51.7
Louisiana	Caddo	63.3	51.5	49.4
Louisiana	Calcasieu	66.3	57.2	56.5
Louisiana	East Baton Rouge	71.0	59.7	57.5
Louisiana	Iberville	66.0	56.1	54.5
Louisiana	Jefferson	66.7	56.1	54.6
Louisiana	Lafourche	63.7	53.4	52.1
Louisiana	Livingston	68.0	57.4	55.5
Louisiana	Pointe Coupee	67.0	57.7	56.3
Louisiana	St. Bernard	65.3	54.6	52.8
Louisiana	St. James	63.3	53.9	52.6
Louisiana	St. John the Baptist	65.0	54.0	52.9
Louisiana	St. Tammany	66.0	53.0	50.9
Louisiana	West Baton Rouge	67.0	56.2	54.0
Maine	Androscoggin	59.3	50.2	48.6
Maine	Cumberland	64.7	54.8	52.7
Maine	Hancock	69.0	58.9	57.5
Maine	Knox	63.3	53.9	52.1
Maine	York	66.0	55.4	53.0
Maryland	Anne Arundel	74.0	62.5	60.6
Maryland	Baltimore	72.7	60.9	59.0
Maryland	Baltimore (City)	68.3	58.1	56.3
Maryland	Calvert	67.7	55.6	53.8
Maryland	Carroll	68.3	54.4	52.0
Maryland	Cecil	74.0	59.7	57.0
Maryland	Charles	69.3	55.9	53.3
Maryland	Dorchester	65.7	55.6	54.5
Maryland	Frederick	68.0	54.4	52.1
Maryland	Harford	74.0	60.8	58.3
Maryland	Kent	69.3	56.2	53.7
Maryland	Montgomery	67.7	53.9	51.0
Maryland	Prince George's	70.7	56.5	53.6
Maryland	Washington	66.7	55.3	53.2
Massachusetts	Barnstable	69.0	57.4	55.2
Massachusetts	Bristol	71.7	67.4	65.8
Massachusetts	Dukes	70.0	60.1	59.0
Massachusetts	Essex	66.3	59.3	58.3
Massachusetts	Hampden	70.0	57.9	55.9
Massachusetts	Hampshire	69.0	56.8	54.7
Massachusetts	Middlesex	64.0	53.3	51.4
Massachusetts	Norfolk	69.0	61.9	60.6
Massachusetts	Plymouth	67.0	55.4	53.4
Massachusetts	Suffolk	60.3	53.5	52.4
Massachusetts	Worcester	66.3	55.9	54.2
Michigan	Allegan	73.7	66.1	64.4
Michigan	Benzie	68.3	59.6	57.8
Michigan	Berrien	73.3	66.0	64.4

State	County	2016 O_3 Design Value (ppb)	2045 ref O_3 Design Value (ppb)	2045 ctl O_3 Design Value (ppb)
Michigan	Cass	72.0	60.7	58.6
Michigan	Chippewa	58.0	51.4	50.9
Michigan	Clinton	67.0	52.9	51.7
Michigan	Huron	67.7	60.8	60.1
Michigan	Ingham	67.7	53.9	52.8
Michigan	Kalamazoo	69.7	56.6	55.0
Michigan	Kent	69.0	58.7	57.3
Michigan	Lenawee	67.0	57.0	55.7
Michigan	Macomb	71.7	60.7	59.2
Michigan	Manistee	67.0	58.1	56.6
Michigan	Mason	68.7	59.2	57.2
Michigan	Muskegon	75.0	67.0	65.1
Michigan	Oakland	70.7	58.7	56.5
Michigan	Ottawa	69.3	60.4	58.7
Michigan	St. Clair	72.0	63.0	61.8
Michigan	Washtenaw	69.3	58.2	56.4
Michigan	Wayne	73.0	60.4	58.4
Minnesota	Anoka	62.7	57.7	56.2
Minnesota	Hennepin	55.7	50.9	49.5
Minnesota	Mille Lacs	60.0	49.0	48.0
Minnesota	Scott	61.3	54.4	53.3
Minnesota	Washington	60.0	52.3	50.8
Mississippi	DeSoto	63.7	52.6	50.3
Mississippi	Hancock	61.7	49.1	47.6
Mississippi	Harrison	65.3	49.5	47.3
Mississippi	Jackson	64.7	47.5	46.0
Missouri	Cass	63.0	53.3	50.9
Missouri	Clay	68.7	59.9	57.6
Missouri	Clinton	67.3	57.6	55.2
Missouri	Jefferson	69.0	56.2	52.6
Missouri	Lincoln	65.0	55.0	52.5
Missouri	Saint Charles	72.7	62.2	58.4
Missouri	Saint Louis	70.0	59.5	55.5
Missouri	Sainte Genevieve	65.3	58.2	57.0
Missouri	St. Louis City	67.3	56.6	52.8
Nebraska	Douglas	63.5	55.1	53.8
Nevada	Carson City	66.7	63.7	63.3
Nevada	Churchill	68.3	65.4	65.1
Nevada	Clark	75.0	63.6	61.8
Nevada	Lyon	69.3	65.3	64.8
Nevada	Washoe	70.0	63.3	62.3
Nevada	White Pine	64.7	62.2	61.8
New Hampshire	Belknap	58.7	47.5	46.6
New Hampshire	Rockingham	66.7	58.2	56.3
New Jersey	Atlantic	63.7	54.7	53.6
New Jersey	Bergen	74.3	66.6	65.1
New Jersey	Camden	75.3	63.5	61.1
New Jersey	Cumberland	65.7	55.2	53.3

State	County	2016 O_3 Design Value (ppb)	2045 ref O_3 Design Value (ppb)	2045 ctl O_3 Design Value (ppb)
New Jersey	Essex	68.3	59.7	57.8
New Jersey	Gloucester	73.7	63.0	61.0
New Jersey	Hudson	71.0	64.1	63.1
New Jersey	Hunterdon	71.3	60.3	57.9
New Jersey	Mercer	73.3	62.5	60.1
New Jersey	Middlesex	74.7	63.6	61.3
New Jersey	Monmouth	67.3	58.8	57.6
New Jersey	Morris	69.0	59.7	57.9
New Jersey	Ocean	72.7	60.9	58.6
New Jersey	Passaic	67.7	58.2	56.6
New Jersey	Warren	64.3	53.5	51.7
New Mexico	Bernalillo	67.3	60.6	59.6
New Mexico	Dona Ana	72.7	68.5	67.4
New Mexico	San Juan	68.0	61.8	61.4
New Mexico	Sandoval	65.7	59.4	58.6
New Mexico	Valencia	65.3	59.5	58.6
New York	Albany	64.0	54.0	52.1
New York	Bronx	70.7	61.3	59.1
New York	Chautauqua	68.0	58.9	57.9
New York	Dutchess	67.0	57.8	56.2
New York	Erie	69.3	63.6	62.4
New York	Jefferson	63.0	53.8	53.4
New York	Monroe	65.7	55.8	54.5
New York	New York	70.3	62.4	60.6
New York	Niagara	66.3	58.7	58.2
New York	Orange	64.3	54.3	52.4
New York	Oswego	61.0	52.2	51.4
New York	Putnam	69.0	60.7	59.1
New York	Queens	72.3	64.2	62.4
New York	Richmond	76.0	73.7	72.9
New York	Rockland	71.3	62.1	60.4
New York	Suffolk	74.3	62.5	60.6
New York	Wayne	65.0	56.5	55.8
New York	Westchester	74.0	63.5	61.1
North Carolina	Alexander	64.3	54.7	53.3
North Carolina	Durham	61.7	48.7	46.4
North Carolina	Forsyth	67.3	52.7	51.0
North Carolina	Guilford	65.3	48.1	46.3
North Carolina	Johnston	63.7	47.7	45.0
North Carolina	Lincoln	66.3	55.8	54.1
North Carolina	Mecklenburg	70.0	56.8	54.0
North Carolina	Rockingham	65.3	41.7	40.4
North Carolina	Rowan	63.7	49.9	47.2
North Carolina	Union	67.7	53.5	50.7
North Carolina	Wake	65.7	50.0	47.3
Ohio	Allen	67.7	55.9	54.2
Ohio	Ashtabula	70.0	60.3	59.3
Ohio	Butler	72.3	60.4	57.6

State	County	2016 O_3 Design Value (ppb)	2045 ref O_3 Design Value (ppb)	2045 ctl O_3 Design Value (ppb)
Ohio	Clark	69.3	56.0	53.7
Ohio	Clermont	70.0	57.5	55.2
Ohio	Clinton	69.7	57.5	55.3
Ohio	Cuyahoga	69.3	61.3	60.4
Ohio	Delaware	65.3	51.8	49.3
Ohio	Fayette	66.7	54.4	52.5
Ohio	Franklin	70.3	56.7	53.8
Ohio	Geauga	71.3	58.1	56.3
Ohio	Greene	67.3	53.9	51.5
Ohio	Hamilton	73.3	61.4	58.5
Ohio	Jefferson	63.0	52.6	51.6
Ohio	Knox	66.5	53.1	51.0
Ohio	Lake	73.7	64.8	63.5
Ohio	Lawrence	66.0	57.4	56.3
Ohio	Licking	65.7	52.0	49.9
Ohio	Lorain	65.7	55.5	53.5
Ohio	Lucas	67.5	56.8	55.9
Ohio	Madison	67.3	55.3	53.4
Ohio	Mahoning	59.7	47.7	46.1
Ohio	Medina	64.3	53.0	51.2
Ohio	Miami	67.7	54.6	52.1
Ohio	Montgomery	70.3	56.9	54.4
Ohio	Portage	62.0	50.5	48.8
Ohio	Preble	67.0	55.6	53.6
Ohio	Stark	68.3	54.7	52.9
Ohio	Summit	63.3	51.6	49.9
Ohio	Trumbull	68.3	54.5	52.7
Ohio	Warren	71.7	58.8	56.3
Ohio	Washington	64.3	49.2	48.5
Ohio	Wood	64.3	54.9	53.7
Oklahoma	Canadian	66.3	53.3	50.7
Oklahoma	Cleveland	66.7	55.3	53.0
Oklahoma	Creek	64.0	52.3	50.9
Oklahoma	Mayes	62.0	51.8	50.8
Oklahoma	McClain	66.3	53.7	51.2
Oklahoma	Oklahoma	69.0	56.0	53.2
Oklahoma	Tulsa	65.0	55.5	54.3
Pennsylvania	Adams	66.5	55.7	54.0
Pennsylvania	Allegheny	69.7	58.4	56.5
Pennsylvania	Armstrong	69.0	58.7	57.6
Pennsylvania	Beaver	68.7	52.0	50.9
Pennsylvania	Berks	70.0	57.9	55.6
Pennsylvania	Blair	63.5	52.1	50.9
Pennsylvania	Bucks	79.3	65.7	62.9
Pennsylvania	Cambria	62.3	49.4	48.3
Pennsylvania	Chester	72.7	59.7	57.4
Pennsylvania	Clearfield	64.7	55.2	54.1
Pennsylvania	Dauphin	66.0	55.4	53.8

State	County	2016 O_3 Design Value (ppb)	2045 ref O_3 Design Value (ppb)	2045 ctl O_3 Design Value (ppb)
Pennsylvania	Delaware	71.3	60.6	58.6
Pennsylvania	Erie	65.0	56.7	55.9
Pennsylvania	Franklin	59.3	49.6	48.0
Pennsylvania	Greene	67.0	58.6	57.5
Pennsylvania	Indiana	69.7	56.1	54.7
Pennsylvania	Lancaster	69.3	56.9	54.6
Pennsylvania	Lawrence	66.3	53.4	52.2
Pennsylvania	Lebanon	69.0	57.4	55.5
Pennsylvania	Lehigh	69.7	58.0	55.8
Pennsylvania	Luzerne	64.0	50.7	49.0
Pennsylvania	Mercer	68.7	55.1	53.4
Pennsylvania	Monroe	66.7	55.0	53.0
Pennsylvania	Montgomery	71.3	61.6	59.5
Pennsylvania	Northampton	70.0	58.1	56.0
Pennsylvania	Philadelphia	77.7	65.4	62.8
Pennsylvania	Somerset	65.0	54.8	53.4
Pennsylvania	Washington	68.0	54.6	53.3
Pennsylvania	Westmoreland	67.0	57.2	55.5
Pennsylvania	York	69.0	56.8	54.4
Rhode Island	Kent	71.3	60.5	58.6
Rhode Island	Providence	69.7	66.2	64.2
Rhode Island	Washington	69.3	64.6	63.5
South Carolina	Anderson	58.5	46.1	43.8
South Carolina	Greenville	63.3	48.9	46.5
South Carolina	Pickens	62.7	49.6	47.3
South Carolina	Richland	64.3	48.1	45.0
South Carolina	Spartanburg	66.0	50.7	48.1
South Carolina	York	64.0	50.7	48.1
Tennessee	Anderson	63.7	48.2	45.6
Tennessee	Blount	67.0	53.4	50.9
Tennessee	Davidson	66.0	52.5	49.5
Tennessee	Hamilton	67.0	50.3	47.0
Tennessee	Jefferson	67.0	51.5	48.9
Tennessee	Knox	66.7	51.2	48.2
Tennessee	Loudon	68.0	52.9	50.4
Tennessee	Shelby	67.3	57.0	54.9
Tennessee	Sullivan	66.0	57.6	56.5
Tennessee	Sumner	66.3	51.1	48.1
Tennessee	Williamson	60.3	47.5	44.6
Tennessee	Wilson	63.5	48.8	46.1
Texas	Bexar	73.0	62.5	60.4
Texas	Brazoria	74.7	65.5	63.1
Texas	Collin	74.3	61.0	58.1
Texas	Dallas	73.7	61.0	58.3
Texas	Denton	78.0	66.1	63.5
Texas	El Paso	71.3	67.9	67.1
Texas	Ellis	64.3	54.0	51.9
Texas	Galveston	75.7	67.3	66.3

State	County	2016 O_3 Design Value (ppb)	2045 ref O_3 Design Value (ppb)	2045 ctl O_3 Design Value (ppb)
Texas	Gregg	65.3	61.8	61.1
Texas	Harris	79.3	71.2	69.0
Texas	Hidalgo	55.0	54.3	53.9
Texas	Johnson	73.7	62.2	59.9
Texas	Orange	61.7	60.8	60.3
Texas	Rockwall	66.0	55.5	53.5
Texas	Tarrant	75.3	63.8	61.2
Utah	Box Elder	67.7	63.3	61.8
Utah	Cache	64.0	60.0	58.7
Utah	Carbon	67.0	60.2	59.7
Utah	Davis	75.7	71.3	69.4
Utah	Salt Lake	76.5	71.9	70.0
Utah	Tooele	73.5	68.5	66.6
Utah	Utah	72.0	68.2	65.9
Utah	Washington	65.7	60.6	59.4
Utah	Weber	73.0	68.4	66.8
Virginia	Arlington	71.0	56.9	54.0
Virginia	Caroline	61.0	48.9	47.0
Virginia	Charles	62.3	47.8	46.5
Virginia	Chesterfield	61.3	47.3	45.9
Virginia	Fairfax	70.0	56.1	53.3
Virginia	Fauquier	58.7	47.7	46.0
Virginia	Frederick	61.3	50.9	49.0
Virginia	Hampton City	64.3	51.1	50.3
Virginia	Hanover	63.3	48.3	46.9
Virginia	Henrico	65.5	50.4	48.9
Virginia	Loudoun	67.0	54.2	52.1
Virginia	Prince William	65.3	54.5	52.8
Virginia	Stafford	62.3	49.3	47.4
Virginia	Suffolk City	61.0	50.6	49.8
Washington	Clark	61.3	52.4	51.0
Washington	King	73.3	63.3	61.6
Washington	Skagit	50.0	45.8	45.8
West Virginia	Berkeley	62.0	51.6	49.6
West Virginia	Gilmer	58.0	52.1	51.3
West Virginia	Hancock	65.5	51.6	50.5
West Virginia	Kanawha	67.0	63.1	62.3
West Virginia	Monongalia	62.3	55.8	55.0
West Virginia	Ohio	67.0	58.0	56.9
West Virginia	Wood	65.0	54.9	53.9
Wisconsin	Brown	65.3	54.7	53.4
Wisconsin	Door	72.7	64.2	62.5
Wisconsin	Kenosha	78.0	70.6	68.7
Wisconsin	Kewaunee	69.3	60.8	59.1
Wisconsin	Manitowoc	73.0	64.2	62.5
Wisconsin	Milwaukee	71.7	64.3	62.9
Wisconsin	Ozaukee	73.3	65.5	63.8
Wisconsin	Racine	76.0	68.4	66.7

State	County	2016 O_3 Design Value (ppb)	2045 ref O_3 Design Value (ppb)	2045 ctl O_3 Design Value (ppb)
Wisconsin	Sheboygan	80.0	71.4	69.5
Wisconsin	Waukesha	65.7	58.1	56.5
Wyoming	Sublette	63.3	61.0	60.6
Wyoming	Sweetwater	66.3	62.4	62.1
Wyoming	Teton	61.0	59.5	59.2
Wyoming	Uinta	61.7	58.0	57.1

Table 6-2 Modeled Annual $PM_{2.5}$ Design Values

State	County	2016 Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Annual $PM_{2.5}$ Design Value (ug/m^3)
Alabama	Baldwin	7.75	7.05	7.00
Alabama	Clay	7.81	7.03	6.99
Alabama	Colbert	7.97	7.12	7.06
Alabama	DeKalb	8.22	7.24	7.18
Alabama	Etowah	8.64	7.61	7.55
Alabama	Houston	7.71	7.03	6.99
Alabama	Jefferson	10.89	9.80	9.72
Alabama	Madison	7.79	6.90	6.85
Alabama	Mobile	8.23	7.48	7.43
Alabama	Montgomery	8.80	7.92	7.86
Alabama	Morgan	7.97	7.11	7.06
Alabama	Talladega	9.17	8.27	8.21
Alabama	Tuscaloosa	8.15	7.29	7.24
Arizona	Cochise	5.43	5.66	5.66
Arizona	La Paz	3.06	2.95	2.95
Arizona	Maricopa	9.68	9.27	9.24
Arizona	Pima	6.12	5.74	5.74
Arizona	Pinal	13.04	12.24	12.13
Arizona	Santa Cruz	9.24	9.30	9.29
Arizona	Yuma	7.59	7.27	7.25
Arkansas	Arkansas	8.41	7.58	7.55
Arkansas	Ashley	8.28	7.62	7.58
Arkansas	Crittenden	8.50	7.69	7.65
Arkansas	Garland	8.55	7.72	7.67
Arkansas	Jackson	8.33	7.52	7.48
Arkansas	Polk	8.39	7.57	7.54
Arkansas	Pulaski	9.93	9.02	8.96
Arkansas	Union	8.87	8.19	8.15
Arkansas	Washington	8.08	7.49	7.46
California	Alameda	10.66	10.28	10.26
California	Butte	9.09	8.40	8.36
California	Calaveras	8.22	7.71	7.65
California	Colusa	7.80	7.27	7.23
California	Contra Costa	9.66	9.32	9.30

State	County	2016 Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Annual $PM_{2.5}$ Design Value (ug/m^3)
California	Fresno	14.24	12.87	12.71
California	Humboldt	6.64	6.53	6.52
California	Imperial	12.41	12.93	12.91
California	Inyo	7.18	7.01	6.99
California	Kern	17.86	15.78	15.63
California	Kings	16.56	14.82	14.63
California	Lake	4.90	4.67	4.65
California	Los Angeles	12.67	12.26	12.24
California	Madera	12.96	11.81	11.68
California	Marin	8.62	8.37	8.36
California	Mendocino	8.01	7.70	7.67
California	Merced	12.63	11.63	11.51
California	Monterey	6.23	6.15	6.15
California	Napa	10.65	10.22	10.17
California	Nevada	6.54	6.15	6.12
California	Orange	7.75	7.43	7.40
California	Placer	7.87	7.39	7.34
California	Plumas	14.95	14.12	14.06
California	Riverside	13.93	13.43	13.39
California	Sacramento	9.78	9.29	9.24
California	San Benito	4.82	4.70	4.68
California	San Bernardino	14.66	14.21	14.19
California	San Diego	9.09	8.89	8.88
California	San Francisco	8.51	8.18	8.16
California	San Joaquin	12.76	12.07	11.96
California	San Luis Obispo	9.73	9.42	9.38
California	San Mateo	8.02	7.85	7.83
California	Santa Barbara	8.02	7.78	7.76
California	Santa Clara	10.07	9.81	9.80
California	Santa Cruz	5.94	5.80	5.78
California	Shasta	7.49	7.09	7.05
California	Siskiyou	8.95	8.71	8.69
California	Solano	9.74	9.39	9.36
California	Sonoma	6.63	6.47	6.46
California	Stanislaus	13.47	12.17	12.02
California	Sutter	9.09	8.52	8.47
California	Tulare	16.00	14.05	13.84
California	Ventura	9.33	9.00	8.97
California	Yolo	7.81	7.26	7.20
Colorado	Arapahoe	5.89	5.53	5.50
Colorado	Boulder	6.88	6.54	6.52
Colorado	Denver	9.20	8.91	8.89
Colorado	Douglas	5.59	5.25	5.23
Colorado	El Paso	5.77	5.45	5.44
Colorado	La Plata	5.80	5.73	5.72
Colorado	Larimer	7.05	6.87	6.85
Colorado	Mesa	6.19	6.03	6.02

State	County	2016 Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Annual $PM_{2.5}$ Design Value (ug/m^3)
Colorado	Pueblo	5.31	5.06	5.05
Colorado	Rio Blanco	7.84	7.60	7.58
Colorado	Weld	8.45	8.04	8.02
Connecticut	Fairfield	8.75	7.97	7.94
Connecticut	Hartford	7.88	7.20	7.17
Connecticut	Litchfield	4.67	4.21	4.20
Connecticut	New Haven	7.13	6.41	6.39
Connecticut	New London	6.07	5.46	5.44
Delaware	New Castle	9.04	8.14	8.08
Delaware	Sussex	7.33	6.47	6.42
District of Columbia	District of Columbia	9.07	8.14	8.09
Florida	Alachua	6.21	5.66	5.63
Florida	Brevard	5.61	5.26	5.25
Florida	Broward	6.60	6.40	6.40
Florida	Citrus	5.86	5.23	5.21
Florida	Duval	7.89	7.46	7.43
Florida	Escambia	7.45	6.86	6.82
Florida	Hillsborough	8.08	7.80	7.76
Florida	Lee	6.17	5.82	5.80
Florida	Leon	7.52	6.89	6.85
Florida	Miami-Dade	7.53	7.38	7.38
Florida	Orange	6.97	6.67	6.64
Florida	Palm Beach	5.98	5.76	5.76
Florida	Pinellas	7.07	6.81	6.80
Florida	Polk	6.60	6.29	6.26
Florida	Sarasota	6.44	6.05	6.03
Florida	Seminole	6.05	5.68	5.66
Florida	Volusia	6.21	5.68	5.65
Georgia	Bibb	9.68	8.84	8.77
Georgia	Chatham	8.23	7.56	7.50
Georgia	Clarke	8.43	7.56	7.50
Georgia	Clayton	9.50	8.53	8.46
Georgia	Cobb	9.06	8.08	8.00
Georgia	DeKalb	8.98	8.05	7.98
Georgia	Dougherty	9.07	8.40	8.35
Georgia	Floyd	9.94	8.79	8.71
Georgia	Fulton	10.32	9.37	9.28
Georgia	Glynn	7.55	6.88	6.84
Georgia	Gwinnett	8.87	7.96	7.88
Georgia	Hall	8.11	7.26	7.19
Georgia	Houston	8.41	7.68	7.63
Georgia	Lowndes	7.75	7.15	7.10
Georgia	Muscogee	9.43	8.71	8.65
Georgia	Paulding	7.82	6.87	6.82
Georgia	Richmond	9.47	8.68	8.62
Georgia	Walker	9.14	8.13	8.05
Georgia	Washington	8.31	7.58	7.53

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Georgia	Wilkinson	9.90	9.03	8.96
Idaho	Ada	7.63	7.25	7.18
Idaho	Bannock	7.44	7.15	7.12
Idaho	Benewah	10.54	10.15	10.12
Idaho	Canyon	9.38	8.98	8.91
Idaho	Franklin	6.96	6.50	6.42
Idaho	Lemhi	12.14	11.77	11.75
Idaho	Shoshone	11.63	11.15	11.12
Illinois	Champaign	7.72	6.89	6.86
Illinois	Cook	10.40	9.43	9.38
Illinois	DuPage	8.56	7.69	7.64
Illinois	Hamilton	8.32	7.35	7.31
Illinois	Kane	8.36	7.52	7.47
Illinois	Macon	8.67	7.71	7.67
Illinois	Madison	9.77	8.80	8.76
Illinois	McHenry	7.59	6.87	6.82
Illinois	McLean	8.34	7.42	7.38
Illinois	Peoria	8.32	7.38	7.34
Illinois	Randolph	8.47	7.56	7.51
Illinois	Rock Island	8.06	7.21	7.17
Illinois	Saint Clair	9.77	8.77	8.72
Illinois	Sangamon	8.40	7.48	7.44
Illinois	Will	7.91	7.01	6.96
Illinois	Winnebago	8.32	7.52	7.47
Indiana	Allen	9.10	8.08	8.04
Indiana	Bartholomew	7.92	6.89	6.83
Indiana	Clark	9.74	8.54	8.48
Indiana	Delaware	8.35	7.39	7.34
Indiana	Dubois	9.12	7.99	7.94
Indiana	Elkhart	9.21	8.28	8.23
Indiana	Floyd	9.24	8.07	8.01
Indiana	Greene	8.27	7.27	7.23
Indiana	Hamilton	8.46	7.43	7.36
Indiana	Henry	7.80	6.87	6.82
Indiana	Howard	8.92	7.97	7.92
Indiana	Lake	9.57	8.74	8.69
Indiana	LaPorte	8.49	7.60	7.54
Indiana	Madison	8.58	7.61	7.56
Indiana	Marion	10.84	9.58	9.51
Indiana	Monroe	8.15	7.13	7.07
Indiana	Porter	8.40	7.58	7.53
Indiana	Spencer	8.90	7.79	7.74
Indiana	St. Joseph	9.53	8.60	8.54
Indiana	Tippecanoe	8.53	7.58	7.53
Indiana	Vanderburgh	9.51	8.47	8.43
Indiana	Vigo	9.53	8.48	8.43
Indiana	Whitley	8.23	7.30	7.25

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Iowa	Black Hawk	8.03	7.24	7.20
Iowa	Clinton	8.78	7.88	7.84
Iowa	Delaware	8.15	7.29	7.25
Iowa	Johnson	7.85	7.02	6.98
Iowa	Lee	8.70	7.79	7.74
Iowa	Linn	8.29	7.45	7.41
Iowa	Montgomery	6.63	5.98	5.96
Iowa	Muscatine	8.81	7.84	7.80
Iowa	Palo Alto	6.93	6.24	6.21
Iowa	Polk	7.46	6.75	6.71
Iowa	Pottawattamie	7.94	7.11	7.08
Iowa	Scott	8.90	7.95	7.91
Iowa	Van Buren	7.13	6.39	6.35
Iowa	Woodbury	7.72	7.01	6.98
Kansas	Johnson	7.38	6.55	6.52
Kansas	Neosho	7.99	7.19	7.16
Kansas	Sedgwick	8.11	7.33	7.31
Kansas	Shawnee	7.94	7.17	7.15
Kansas	Sumner	7.16	6.46	6.44
Kansas	Wyandotte	8.94	8.02	7.99
Kentucky	Bell	8.86	7.99	7.95
Kentucky	Boyd	8.04	7.07	7.04
Kentucky	Campbell	8.48	7.35	7.29
Kentucky	Carter	6.79	5.86	5.83
Kentucky	Christian	8.65	7.61	7.55
Kentucky	Daviess	8.99	7.84	7.79
Kentucky	Fayette	8.47	7.28	7.23
Kentucky	Hardin	8.63	7.40	7.34
Kentucky	Henderson	9.10	8.09	8.04
Kentucky	Jefferson	10.04	8.82	8.76
Kentucky	Madison	7.85	6.75	6.70
Kentucky	McCracken	8.71	7.63	7.58
Kentucky	Perry	8.04	7.20	7.16
Kentucky	Pike	7.55	6.72	6.70
Kentucky	Pulaski	8.01	6.99	6.94
Kentucky	Warren	8.32	7.26	7.20
Louisiana	Caddo	10.20	9.52	9.47
Louisiana	Calcasieu	7.53	7.04	7.01
Louisiana	East Baton Rouge	9.09	8.63	8.61
Louisiana	Iberville	8.41	8.08	8.06
Louisiana	Jefferson	7.44	7.02	7.01
Louisiana	Lafayette	7.71	7.27	7.25
Louisiana	Orleans	8.07	7.60	7.58
Louisiana	Ouachita	8.05	7.41	7.37
Louisiana	St. Bernard	8.63	8.12	8.10
Louisiana	Tangipahoa	7.43	6.80	6.75
Louisiana	Terrebonne	7.14	6.75	6.74

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Louisiana	West Baton Rouge	9.07	8.61	8.59
Maine	Androscoggin	6.68	6.07	6.05
Maine	Aroostook	7.50	6.95	6.95
Maine	Cumberland	6.81	6.23	6.21
Maine	Hancock	3.90	3.60	3.59
Maine	Kennebec	5.51	5.01	4.99
Maine	Oxford	6.54	6.00	5.98
Maine	Penobscot	6.34	5.82	5.80
Maryland	Anne Arundel	8.99	7.96	7.91
Maryland	Baltimore	8.79	7.77	7.71
Maryland	Baltimore (City)	9.24	8.12	8.06
Maryland	Cecil	8.32	7.51	7.45
Maryland	Dorchester	7.70	6.86	6.81
Maryland	Garrett	5.64	4.97	4.96
Maryland	Harford	8.17	7.26	7.20
Maryland	Howard	9.07	8.14	8.09
Maryland	Kent	7.61	6.81	6.76
Maryland	Montgomery	7.58	6.70	6.66
Maryland	Prince George's	8.16	7.29	7.25
Maryland	Washington	8.37	7.45	7.40
Massachusetts	Berkshire	6.17	5.62	5.59
Massachusetts	Bristol	6.19	5.66	5.64
Massachusetts	Essex	5.64	5.11	5.09
Massachusetts	Franklin	5.55	5.07	5.05
Massachusetts	Hampden	6.81	6.24	6.21
Massachusetts	Hampshire	5.08	4.60	4.58
Massachusetts	Plymouth	5.46	4.92	4.90
Massachusetts	Suffolk	7.18	6.50	6.48
Massachusetts	Worcester	6.04	5.52	5.50
Michigan	Allegan	7.55	6.82	6.77
Michigan	Bay	7.20	6.54	6.50
Michigan	Berrien	7.91	7.13	7.08
Michigan	Genesee	7.60	6.78	6.74
Michigan	Ingham	8.06	7.22	7.17
Michigan	Kalamazoo	8.51	7.67	7.62
Michigan	Kent	9.23	8.43	8.37
Michigan	Lenawee	7.93	7.09	7.03
Michigan	Macomb	8.20	7.37	7.32
Michigan	Manistee	5.91	5.32	5.28
Michigan	Missaukee	5.16	4.64	4.62
Michigan	Monroe	8.46	7.59	7.54
Michigan	Oakland	8.47	7.50	7.45
Michigan	St. Clair	8.43	7.67	7.63
Michigan	Washtenaw	8.51	7.66	7.61
Michigan	Wayne	11.22	10.14	10.09
Minnesota	Anoka	6.81	6.26	6.24
Minnesota	Becker	5.01	4.68	4.67

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Minnesota	Beltrami	5.42	5.13	5.12
Minnesota	Carlton	4.79	4.50	4.48
Minnesota	Cook	4.38	4.18	4.17
Minnesota	Crow Wing	5.72	5.32	5.30
Minnesota	Dakota	6.82	6.31	6.28
Minnesota	Hennepin	8.03	7.41	7.38
Minnesota	Lake	3.88	3.70	3.70
Minnesota	Lyon	5.16	4.67	4.65
Minnesota	Olmsted	6.85	6.26	6.23
Minnesota	Ramsey	7.93	7.36	7.33
Minnesota	Saint Louis	5.32	5.02	5.01
Minnesota	Scott	6.74	6.18	6.15
Minnesota	Stearns	5.84	5.36	5.34
Minnesota	Washington	6.59	6.08	6.05
Minnesota	Wright	6.37	5.89	5.86
Mississippi	DeSoto	7.62	6.86	6.82
Mississippi	Forrest	8.77	7.95	7.89
Mississippi	Grenada	7.27	6.49	6.45
Mississippi	Hancock	8.02	7.37	7.33
Mississippi	Harrison	7.88	7.22	7.18
Mississippi	Hinds	8.78	7.90	7.84
Mississippi	Jackson	8.09	7.35	7.30
Missouri	Buchanan	8.93	8.05	8.01
Missouri	Cass	7.43	6.60	6.56
Missouri	Cedar	7.01	6.24	6.20
Missouri	Clay	7.08	6.28	6.25
Missouri	Greene	7.38	6.62	6.58
Missouri	Jackson	8.86	7.95	7.91
Missouri	Jefferson	9.11	8.21	8.17
Missouri	Saint Louis	9.48	8.52	8.47
Missouri	St. Louis City	9.14	8.17	8.12
Montana	Fergus	4.89	4.78	4.77
Montana	Flathead	8.72	8.36	8.34
Montana	Gallatin	3.98	3.94	3.94
Montana	Lewis and Clark	9.20	8.88	8.86
Montana	Lincoln	12.43	11.91	11.88
Montana	Missoula	10.63	10.23	10.20
Montana	Phillips	5.44	5.35	5.34
Montana	Powder River	7.31	7.11	7.10
Montana	Ravalli	10.33	10.07	10.05
Montana	Richland	6.46	6.34	6.33
Montana	Rosebud	6.15	6.00	5.99
Montana	Silver Bow	9.33	8.94	8.91
Nebraska	Douglas	8.73	7.89	7.87
Nebraska	Hall	5.92	5.48	5.47
Nebraska	Lancaster	6.63	6.03	6.01
Nebraska	Sarpy	8.77	7.92	7.89

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Nebraska	Washington	6.81	6.10	6.08
Nevada	Carson City	5.24	5.00	4.98
Nevada	Clark	9.85	9.24	9.22
Nevada	Douglas	7.74	7.41	7.39
Nevada	Washoe	7.68	7.33	7.30
New Hampshire	Belknap	4.62	4.20	4.19
New Hampshire	Cheshire	6.59	6.08	6.07
New Hampshire	Grafton	5.83	5.42	5.40
New Hampshire	Hillsborough	4.55	4.18	4.17
New Hampshire	Rockingham	5.71	5.23	5.20
New Jersey	Atlantic	7.24	6.62	6.60
New Jersey	Bergen	8.32	7.51	7.48
New Jersey	Camden	10.24	9.22	9.17
New Jersey	Essex	8.64	7.89	7.86
New Jersey	Gloucester	8.33	7.49	7.46
New Jersey	Hudson	8.45	7.70	7.67
New Jersey	Mercer	8.18	7.45	7.41
New Jersey	Middlesex	8.22	7.59	7.56
New Jersey	Morris	6.38	5.76	5.73
New Jersey	Ocean	6.91	6.19	6.16
New Jersey	Passaic	8.01	7.23	7.19
New Jersey	Union	9.58	8.67	8.63
New Jersey	Warren	8.42	7.66	7.61
New Mexico	Bernalillo	7.38	7.05	7.04
New Mexico	Dona Ana	8.68	8.74	8.73
New Mexico	Lea	7.38	7.28	7.27
New York	Albany	7.00	6.38	6.35
New York	Bronx	8.60	7.79	7.76
New York	Chautauqua	6.69	5.95	5.93
New York	Erie	7.66	6.83	6.81
New York	Essex	3.77	3.47	3.46
New York	Kings	8.21	7.47	7.44
New York	Monroe	6.89	6.14	6.12
New York	New York	9.79	8.97	8.94
New York	Onondaga	5.52	4.92	4.90
New York	Orange	6.57	5.92	5.89
New York	Queens	7.26	6.56	6.53
New York	Richmond	7.51	6.74	6.71
New York	Steuben	4.99	4.41	4.39
New York	Suffolk	6.91	6.15	6.12
North Carolina	Buncombe	7.42	6.80	6.76
North Carolina	Catawba	8.73	8.12	8.06
North Carolina	Cumberland	8.30	7.57	7.51
North Carolina	Davidson	8.69	8.02	7.96
North Carolina	Durham	8.71	8.04	7.99
North Carolina	Forsyth	7.74	7.00	6.95
North Carolina	Guilford	8.10	7.39	7.34

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North Carolina	Jackson	7.79	7.14	7.11
North Carolina	Johnston	7.52	6.85	6.80
North Carolina	Mecklenburg	8.76	8.17	8.10
North Carolina	Mitchell	7.45	6.80	6.77
North Carolina	Montgomery	6.67	6.08	6.04
North Carolina	New Hanover	5.48	5.00	4.97
North Carolina	Pitt	6.92	6.27	6.24
North Carolina	Swain	8.17	7.52	7.49
North Carolina	Wake	8.77	8.14	8.08
North Dakota	Billings	4.07	3.94	3.93
North Dakota	Burke	3.76	3.62	3.62
North Dakota	Burleigh	4.84	4.52	4.51
North Dakota	Cass	6.36	5.96	5.95
North Dakota	Dunn	5.45	5.26	5.25
North Dakota	McKenzie	3.57	3.48	3.48
North Dakota	Mercer	3.95	3.73	3.72
North Dakota	Oliver	4.81	4.52	4.52
North Dakota	Williams	4.36	4.26	4.25
Ohio	Allen	8.32	7.43	7.39
Ohio	Athens	6.76	5.82	5.80
Ohio	Belmont	7.89	6.84	6.81
Ohio	Butler	10.79	9.86	9.82
Ohio	Clark	8.77	7.85	7.83
Ohio	Cuyahoga	11.60	10.38	10.33
Ohio	Franklin	9.27	8.26	8.22
Ohio	Greene	8.08	7.19	7.17
Ohio	Hamilton	10.17	8.99	8.93
Ohio	Jefferson	10.64	9.21	9.17
Ohio	Lake	7.42	6.56	6.52
Ohio	Lawrence	6.85	6.00	5.97
Ohio	Lorain	7.72	6.84	6.80
Ohio	Lucas	9.59	8.68	8.63
Ohio	Mahoning	9.29	8.18	8.14
Ohio	Medina	8.21	7.16	7.11
Ohio	Montgomery	8.71	7.86	7.85
Ohio	Portage	7.52	6.46	6.42
Ohio	Preble	7.97	7.06	7.00
Ohio	Scioto	8.35	7.24	7.20
Ohio	Stark	10.05	8.91	8.87
Ohio	Summit	10.05	8.74	8.69
Ohio	Trumbull	7.81	6.81	6.77
Oklahoma	Cleveland	8.25	7.60	7.57
Oklahoma	Comanche	7.21	6.72	6.71
Oklahoma	Kay	7.75	7.07	7.04
Oklahoma	Oklahoma	8.25	7.61	7.58
Oklahoma	Pittsburg	7.96	7.20	7.17
Oklahoma	Sequoyah	8.27	7.60	7.56

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Oklahoma	Tulsa	9.02	8.24	8.21
Oregon	Crook	8.94	8.53	8.50
Oregon	Harney	9.15	8.70	8.66
Oregon	Jackson	10.52	10.12	10.08
Oregon	Josephine	8.81	8.43	8.40
Oregon	Klamath	9.97	9.66	9.63
Oregon	Lake	8.13	7.82	7.80
Oregon	Lane	9.22	8.87	8.84
Oregon	Multnomah	6.77	6.51	6.50
Oregon	Washington	7.32	7.05	7.03
Pennsylvania	Adams	8.16	7.38	7.33
Pennsylvania	Allegheny	12.81	11.17	11.14
Pennsylvania	Armstrong	10.26	9.11	9.08
Pennsylvania	Beaver	9.59	8.41	8.38
Pennsylvania	Berks	9.05	8.16	8.10
Pennsylvania	Blair	9.14	7.96	7.93
Pennsylvania	Bradford	7.01	6.39	6.36
Pennsylvania	Cambria	10.39	9.08	9.05
Pennsylvania	Centre	8.08	7.10	7.06
Pennsylvania	Chester	9.84	8.99	8.93
Pennsylvania	Cumberland	8.68	7.89	7.83
Pennsylvania	Dauphin	9.36	8.45	8.39
Pennsylvania	Delaware	10.82	9.98	9.94
Pennsylvania	Erie	8.56	7.63	7.59
Pennsylvania	Greene	6.22	5.35	5.33
Pennsylvania	Lackawanna	8.70	8.03	7.98
Pennsylvania	Lancaster	11.14	10.14	10.07
Pennsylvania	Lebanon	10.18	9.13	9.06
Pennsylvania	Lehigh	9.04	8.22	8.17
Pennsylvania	Mercer	9.43	8.36	8.32
Pennsylvania	Monroe	7.37	6.60	6.56
Pennsylvania	Northampton	8.92	8.11	8.06
Pennsylvania	Philadelphia	10.70	9.77	9.72
Pennsylvania	Tioga	8.08	7.36	7.32
Pennsylvania	Washington	9.64	8.35	8.33
Pennsylvania	Westmoreland	8.94	7.94	7.91
Pennsylvania	York	9.61	8.62	8.55
Rhode Island	Kent	4.77	4.28	4.27
Rhode Island	Providence	8.97	8.32	8.29
Rhode Island	Washington	5.31	4.84	4.83
South Carolina	Charleston	7.19	6.58	6.53
South Carolina	Chesterfield	7.47	6.78	6.73
South Carolina	Edgefield	8.38	7.58	7.51
South Carolina	Florence	8.63	7.76	7.69
South Carolina	Greenville	8.93	8.40	8.34
South Carolina	Lexington	8.64	7.85	7.78
South Carolina	Richland	8.86	8.05	7.98

State	County	2016 Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Annual $PM_{2.5}$ Design Value (ug/m^3)
South Carolina	Spartanburg	8.35	7.75	7.68
South Dakota	Brookings	4.83	4.39	4.37
South Dakota	Brown	5.92	5.55	5.53
South Dakota	Codington	6.28	5.83	5.81
South Dakota	Custer	3.36	3.25	3.25
South Dakota	Hughes	4.04	3.85	3.84
South Dakota	Jackson	3.62	3.49	3.48
South Dakota	Minnehaha	6.78	6.19	6.16
South Dakota	Pennington	7.27	7.02	7.00
South Dakota	Union	6.82	6.21	6.18
Tennessee	Blount	8.12	7.36	7.31
Tennessee	Davidson	8.99	8.17	8.10
Tennessee	Dyer	7.11	6.35	6.32
Tennessee	Hamilton	8.48	7.56	7.49
Tennessee	Knox	9.91	8.89	8.82
Tennessee	Lawrence	6.85	6.08	6.04
Tennessee	Loudon	8.65	7.88	7.81
Tennessee	Madison	7.04	6.23	6.19
Tennessee	Maury	6.95	6.15	6.10
Tennessee	McMinn	8.36	7.51	7.44
Tennessee	Montgomery	8.16	7.18	7.12
Tennessee	Putnam	7.44	6.58	6.54
Tennessee	Roane	8.12	7.31	7.25
Tennessee	Shelby	8.50	7.68	7.64
Tennessee	Sullivan	7.55	6.81	6.77
Tennessee	Sumner	7.93	7.11	7.05
Texas	Bexar	8.28	7.76	7.74
Texas	Cameron	9.87	9.95	9.94
Texas	Dallas	9.10	8.22	8.19
Texas	El Paso	9.13	9.42	9.41
Texas	Galveston	6.91	6.53	6.52
Texas	Harris	10.67	10.33	10.32
Texas	Harrison	8.64	7.86	7.81
Texas	Hidalgo	10.33	10.29	10.28
Texas	Nueces	9.45	9.03	9.02
Texas	Tarrant	8.75	8.02	8.00
Texas	Travis	9.67	9.08	9.05
Utah	Box Elder	7.10	6.51	6.40
Utah	Cache	7.60	7.03	6.92
Utah	Davis	7.81	7.24	7.10
Utah	Duchesne	6.20	5.88	5.84
Utah	Salt Lake	8.76	8.14	8.01
Utah	Tooele	6.97	6.67	6.60
Utah	Utah	8.08	7.51	7.38
Utah	Washington	5.04	4.88	4.85
Utah	Weber	8.69	8.00	7.85
Vermont	Bennington	5.58	5.12	5.10

State	County	2016 Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Annual $PM_{2.5}$ Design Value (ug/m^3)
Vermont	Chittenden	5.77	5.24	5.22
Vermont	Rutland	7.52	7.08	7.06
Virginia	Albemarle	6.85	6.09	6.05
Virginia	Arlington	8.03	7.12	7.08
Virginia	Bristol City	7.63	6.89	6.85
Virginia	Charles	6.98	6.22	6.18
Virginia	Chesterfield	8.03	7.23	7.19
Virginia	Fairfax	7.22	6.36	6.31
Virginia	Frederick	7.94	7.07	7.03
Virginia	Hampton City	6.60	5.93	5.90
Virginia	Henrico	7.38	6.60	6.56
Virginia	Loudoun	7.70	6.92	6.88
Virginia	Lynchburg City	6.83	6.04	6.01
Virginia	Norfolk City	7.08	6.41	6.38
Virginia	Roanoke	7.05	6.20	6.17
Virginia	Rockingham	7.55	6.77	6.74
Virginia	Salem City	7.70	6.80	6.77
Virginia	Virginia Beach City	7.11	6.46	6.43
Washington	Chelan	5.61	5.33	5.31
Washington	Clark	7.52	7.26	7.25
Washington	King	8.53	8.42	8.41
Washington	Kitsap	4.65	4.46	4.46
Washington	Kittitas	7.84	7.31	7.27
Washington	Pierce	7.70	7.54	7.53
Washington	Skagit	5.85	5.69	5.68
Washington	Snohomish	7.37	7.20	7.19
Washington	Spokane	9.57	9.19	9.16
Washington	Whatcom	5.93	5.74	5.73
Washington	Yakima	9.38	8.58	8.52
West Virginia	Berkeley	9.22	8.24	8.19
West Virginia	Brooke	9.75	8.37	8.33
West Virginia	Hancock	8.37	7.18	7.15
West Virginia	Harrison	7.92	6.99	6.97
West Virginia	Kanawha	8.28	7.25	7.22
West Virginia	Marshall	9.67	8.47	8.43
West Virginia	Monongalia	7.63	6.66	6.63
West Virginia	Ohio	8.75	7.48	7.45
West Virginia	Wood	8.45	7.44	7.40
Wisconsin	Ashland	4.35	4.02	4.00
Wisconsin	Brown	7.13	6.57	6.53
Wisconsin	Dane	8.16	7.44	7.39
Wisconsin	Dodge	7.12	6.49	6.44
Wisconsin	Eau Claire	6.83	6.22	6.18
Wisconsin	Forest	4.38	3.99	3.97
Wisconsin	Grant	7.39	6.60	6.56
Wisconsin	Kenosha	7.49	6.76	6.72
Wisconsin	La Crosse	6.94	6.33	6.30

State	County	2016 Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Annual $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Annual $PM_{2.5}$ Design Value (ug/m^3)
Wisconsin	Milwaukee	8.50	7.78	7.73
Wisconsin	Outagamie	6.83	6.26	6.21
Wisconsin	Ozaukee	6.85	6.26	6.21
Wisconsin	Sauk	6.69	6.02	5.97
Wisconsin	Taylor	5.68	5.20	5.17
Wisconsin	Vilas	4.62	4.27	4.25
Wisconsin	Waukesha	8.57	7.85	7.79
Wyoming	Albany	4.34	4.17	4.16
Wyoming	Campbell	4.50	4.40	4.40
Wyoming	Fremont	6.85	6.65	6.64
Wyoming	Laramie	4.21	4.04	4.03
Wyoming	Natrona	4.85	4.67	4.67
Wyoming	Park	4.14	4.04	4.03
Wyoming	Sheridan	7.18	6.97	6.95
Wyoming	Sublette	5.13	5.02	5.01
Wyoming	Sweetwater	5.06	4.76	4.73
Wyoming	Teton	4.62	4.50	4.49

Table 6-3 Modeled Daily $PM_{2.5}$ Design Values

State	County	2016 Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Daily $PM_{2.5}$ Design Value (ug/m^3)
Alabama	Baldwin	16.62	15.11	15.25
Alabama	Clay	17.23	15.55	15.69
Alabama	Colbert	16.47	14.37	14.52
Alabama	DeKalb	16.22	14.17	14.33
Alabama	Etowah	16.44	14.29	14.50
Alabama	Houston	15.71	14.29	14.40
Alabama	Jefferson	22.00	19.69	19.90
Alabama	Madison	15.84	14.02	14.20
Alabama	Mobile	17.20	15.47	15.62
Alabama	Montgomery	18.97	17.26	17.41
Alabama	Morgan	15.90	13.66	13.84
Alabama	Talladega	18.05	16.10	16.26
Alabama	Tuscaloosa	16.41	14.51	14.65
Arizona	Cochise	11.83	12.39	12.40
Arizona	La Paz	9.41	9.24	9.25
Arizona	Maricopa	27.30	26.16	26.21
Arizona	Pima	15.63	14.93	14.97
Arizona	Pinal	35.53	31.84	32.32
Arizona	Santa Cruz	27.09	26.92	26.96
Arizona	Yuma	20.69	19.89	20.01
Arkansas	Arkansas	18.44	16.89	16.98
Arkansas	Ashley	17.71	16.15	16.25
Arkansas	Crittenden	17.81	16.02	16.13

State	County	2016 Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Daily $PM_{2.5}$ Design Value (ug/m^3)
Arkansas	Garland	17.77	15.85	15.97
Arkansas	Jackson	20.33	18.68	18.77
Arkansas	Polk	18.78	17.11	17.19
Arkansas	Pulaski	21.27	19.00	19.19
Arkansas	Union	18.42	17.25	17.35
Arkansas	Washington	18.43	16.56	16.67
California	Alameda	41.27	38.51	38.81
California	Butte	30.58	27.83	28.04
California	Calaveras	20.10	17.65	17.91
California	Colusa	26.16	24.08	24.30
California	Contra Costa	32.22	30.44	30.68
California	Fresno	55.37	49.17	49.86
California	Humboldt	20.86	20.57	20.60
California	Imperial	33.10	32.16	32.29
California	Inyo	28.00	27.43	27.48
California	Kern	63.10	55.29	55.78
California	Kings	60.26	45.81	47.23
California	Lake	10.00	9.58	9.63
California	Los Angeles	36.74	32.90	33.79
California	Madera	43.59	37.87	38.49
California	Marin	30.20	28.76	28.95
California	Mendocino	25.82	24.51	24.64
California	Merced	40.91	34.44	35.12
California	Monterey	28.81	28.60	28.63
California	Napa	30.25	28.65	28.89
California	Nevada	26.77	25.18	25.33
California	Orange	31.40	29.43	29.91
California	Placer	23.63	21.66	21.91
California	Plumas	48.87	46.14	46.30
California	Riverside	39.69	36.84	37.35
California	Sacramento	33.97	31.29	31.71
California	San Benito	16.68	15.91	15.99
California	San Bernardino	35.40	33.09	33.29
California	San Diego	22.09	21.68	21.74
California	San Francisco	30.52	27.75	27.96
California	San Joaquin	44.51	36.93	38.15
California	San Luis Obispo	25.42	24.55	24.63
California	San Mateo	26.43	25.02	25.24
California	Santa Barbara	21.18	20.48	20.55
California	Santa Clara	35.13	31.89	32.40
California	Santa Cruz	19.45	17.42	17.69
California	Shasta	28.66	26.89	27.07
California	Siskiyou	44.38	44.02	44.04
California	Solano	34.28	32.44	32.67
California	Sonoma	24.17	22.72	22.89
California	Stanislaus	49.54	38.28	39.54
California	Sutter	28.32	26.25	26.44
California	Tulare	55.74	40.84	42.63

State	County	2016 Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Daily $PM_{2.5}$ Design Value (ug/m^3)
California	Ventura	33.98	32.41	32.58
California	Yolo	30.10	27.48	27.85
Colorado	Arapahoe	17.30	17.70	17.71
Colorado	Boulder	24.08	23.94	23.95
Colorado	Denver	24.07	23.97	23.97
Colorado	Douglas	19.66	19.39	19.41
Colorado	El Paso	15.50	15.20	15.22
Colorado	La Plata	18.86	18.63	18.65
Colorado	Larimer	20.47	20.60	20.62
Colorado	Mesa	18.57	18.50	18.52
Colorado	Pueblo	14.60	14.26	14.27
Colorado	Rio Blanco	14.52	14.08	14.11
Colorado	Weld	25.46	25.17	25.18
Connecticut	Fairfield	21.99	20.62	20.62
Connecticut	Hartford	19.03	17.43	17.50
Connecticut	Litchfield	13.31	11.56	11.60
Connecticut	New Haven	19.48	17.95	17.99
Connecticut	New London	16.57	15.13	15.19
Delaware	New Castle	23.00	21.24	21.33
Delaware	Sussex	16.84	15.24	15.35
District of Columbia	District of Columbia	20.59	19.57	19.61
Florida	Alachua	14.80	13.13	13.25
Florida	Brevard	13.16	12.53	12.58
Florida	Broward	15.64	15.68	15.70
Florida	Citrus	12.87	11.33	11.40
Florida	Duval	17.13	16.17	16.25
Florida	Escambia	15.38	13.85	13.96
Florida	Hillsborough	17.66	16.50	16.63
Florida	Lee	13.10	12.24	12.31
Florida	Leon	17.57	16.38	16.47
Florida	Miami-Dade	15.72	16.10	16.10
Florida	Orange	15.18	14.67	14.75
Florida	Palm Beach	13.34	13.48	13.49
Florida	Pinellas	17.23	16.65	16.71
Florida	Polk	13.90	13.08	13.14
Florida	Sarasota	14.59	13.49	13.56
Florida	Seminole	14.47	13.58	13.65
Florida	Volusia	13.16	12.08	12.16
Georgia	Bibb	20.03	18.46	18.56
Georgia	Chatham	20.18	18.31	18.44
Georgia	Clarke	17.38	15.33	15.54
Georgia	Clayton	18.49	16.60	16.80
Georgia	Cobb	17.87	16.21	16.37
Georgia	DeKalb	19.29	17.72	17.88
Georgia	Dougherty	22.36	21.47	21.51
Georgia	Floyd	19.93	17.48	17.75
Georgia	Fulton	21.82	19.98	20.10
Georgia	Glynn	22.58	20.28	20.50

State	County	2016 Daily $PM_{2.5}$ Design Value (ug/m³)	2045 ctl Daily $PM_{2.5}$ Design Value (ug/m³)	2045 ref Daily $PM_{2.5}$ Design Value (ug/m³)
Georgia	Gwinnett	19.37	18.07	18.24
Georgia	Hall	19.34	17.53	17.75
Georgia	Houston	18.34	17.14	17.26
Georgia	Lowndes	17.48	16.26	16.33
Georgia	Muscogee	28.33	27.47	27.53
Georgia	Paulding	16.20	14.18	14.39
Georgia	Richmond	23.33	21.26	21.46
Georgia	Walker	18.58	16.89	17.01
Georgia	Washington	21.51	19.53	19.70
Georgia	Wilkinson	21.17	19.36	19.53
Idaho	Ada	30.88	30.36	30.45
Idaho	Bannock	25.43	24.47	24.54
Idaho	Benewah	38.23	36.59	36.72
Idaho	Canyon	33.57	32.97	33.06
Idaho	Franklin	30.13	29.30	29.29
Idaho	Lemhi	43.53	42.39	42.46
Idaho	Shoshone	38.71	36.91	37.07
Illinois	Champaign	16.73	14.04	14.18
Illinois	Cook	23.20	20.89	21.12
Illinois	DuPage	19.95	17.92	18.13
Illinois	Hamilton	17.68	15.25	15.36
Illinois	Kane	19.08	17.35	17.47
Illinois	Macon	18.50	15.93	16.13
Illinois	Madison	21.48	18.42	18.59
Illinois	McHenry	16.93	15.32	15.49
Illinois	McLean	17.90	15.49	15.67
Illinois	Peoria	18.25	16.02	16.14
Illinois	Randolph	18.10	15.84	16.00
Illinois	Rock Island	20.30	17.72	17.91
Illinois	Saint Clair	19.62	17.28	17.43
Illinois	Sangamon	20.03	17.10	17.27
Illinois	Will	18.60	16.52	16.76
Illinois	Winnebago	18.03	15.98	16.13
Indiana	Allen	21.84	19.37	19.57
Indiana	Bartholomew	17.62	15.14	15.32
Indiana	Clark	22.39	19.52	19.68
Indiana	Delaware	18.89	16.65	16.80
Indiana	Dubois	21.12	18.25	18.42
Indiana	Elkhart	25.11	22.95	23.12
Indiana	Floyd	19.90	17.54	17.69
Indiana	Greene	19.91	17.75	17.90
Indiana	Hamilton	19.43	17.39	17.60
Indiana	Henry	17.09	15.23	15.39
Indiana	Howard	19.88	17.89	18.03
Indiana	Lake	23.46	21.49	21.65
Indiana	LaPorte	20.75	18.90	19.06
Indiana	Madison	19.59	17.27	17.45
Indiana	Marion	24.44	21.78	21.95

State	County	2016 Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Daily $PM_{2.5}$ Design Value (ug/m^3)
Indiana	Monroe	17.88	15.34	15.51
Indiana	Porter	20.56	18.94	19.09
Indiana	Spencer	19.82	17.12	17.26
Indiana	St. Joseph	22.09	20.18	20.35
Indiana	Tippecanoe	19.67	17.61	17.81
Indiana	Vanderburgh	20.20	17.59	17.72
Indiana	Vigo	22.07	19.04	19.21
Indiana	Whitley	20.48	18.30	18.48
Iowa	Black Hawk	20.32	17.47	17.73
Iowa	Clinton	21.38	18.76	18.96
Iowa	Delaware	20.60	17.29	17.62
Iowa	Johnson	19.16	16.52	16.74
Iowa	Lee	19.52	16.61	16.77
Iowa	Linn	20.48	17.76	17.92
Iowa	Montgomery	16.56	14.49	14.65
Iowa	Muscatine	23.17	19.92	20.14
Iowa	Palo Alto	16.71	14.27	14.43
Iowa	Polk	17.98	15.55	15.74
Iowa	Pottawattamie	18.64	16.05	16.19
Iowa	Scott	22.74	19.90	20.11
Iowa	Van Buren	18.42	15.54	15.81
Iowa	Woodbury	18.03	15.63	15.76
Kansas	Johnson	17.28	15.46	15.60
Kansas	Neosho	18.73	17.21	17.30
Kansas	Sedgwick	21.97	20.31	20.39
Kansas	Shawnee	19.71	18.16	18.23
Kansas	Sumner	18.31	16.67	16.72
Kansas	Wyandotte	21.87	19.62	19.74
Kentucky	Bell	25.16	23.72	23.83
Kentucky	Boyd	17.58	15.66	15.73
Kentucky	Campbell	19.16	17.35	17.45
Kentucky	Carter	16.16	13.77	13.89
Kentucky	Christian	18.70	15.83	16.01
Kentucky	Daviess	19.47	16.79	16.92
Kentucky	Fayette	18.45	15.98	16.11
Kentucky	Hardin	18.07	15.90	16.06
Kentucky	Henderson	18.86	15.96	16.10
Kentucky	Jefferson	21.38	19.22	19.35
Kentucky	Madison	17.78	15.56	15.68
Kentucky	McCracken	18.21	16.02	16.15
Kentucky	Perry	19.16	17.96	18.00
Kentucky	Pike	20.18	18.87	18.93
Kentucky	Pulaski	17.57	15.00	15.13
Kentucky	Warren	17.84	14.59	14.79
Louisiana	Caddo	20.90	19.75	19.84
Louisiana	Calcasieu	18.47	17.13	17.21
Louisiana	East Baton Rouge	21.09	20.51	20.53
Louisiana	Iberville	19.20	18.61	18.67

State	County	2016 Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Daily $PM_{2.5}$ Design Value (ug/m^3)
Louisiana	Jefferson	17.98	17.10	17.15
Louisiana	Lafayette	16.43	15.53	15.60
Louisiana	Orleans	17.92	16.89	16.96
Louisiana	Ouachita	19.90	18.50	18.60
Louisiana	St. Bernard	18.84	17.36	17.44
Louisiana	Tangipahoa	16.10	14.80	14.89
Louisiana	Terrebonne	15.79	14.80	14.86
Louisiana	West Baton Rouge	18.97	18.30	18.36
Maine	Androscoggin	16.73	14.96	15.02
Maine	Aroostook	18.88	17.11	17.12
Maine	Cumberland	16.67	14.98	15.07
Maine	Hancock	11.37	10.24	10.29
Maine	Kennebec	15.47	13.90	13.96
Maine	Oxford	19.83	17.96	17.98
Maine	Penobscot	15.17	13.64	13.68
Maryland	Anne Arundel	21.53	20.49	20.53
Maryland	Baltimore	21.59	20.08	20.15
Maryland	Baltimore (City)	23.13	21.26	21.33
Maryland	Cecil	20.57	18.89	18.94
Maryland	Dorchester	17.18	15.56	15.62
Maryland	Garrett	13.93	12.18	12.23
Maryland	Harford	20.13	18.92	18.97
Maryland	Howard	19.72	18.64	18.67
Maryland	Kent	17.41	15.67	15.74
Maryland	Montgomery	17.77	16.60	16.64
Maryland	Prince George's	17.94	17.12	17.17
Maryland	Washington	20.47	19.17	19.18
Massachusetts	Berkshire	15.56	13.89	13.95
Massachusetts	Bristol	15.01	13.79	13.82
Massachusetts	Essex	15.38	13.69	13.79
Massachusetts	Franklin	14.91	13.54	13.62
Massachusetts	Hampden	17.73	16.19	16.24
Massachusetts	Hampshire	14.33	12.88	12.98
Massachusetts	Plymouth	15.80	13.93	14.03
Massachusetts	Suffolk	16.76	15.04	15.10
Massachusetts	Worcester	15.78	14.38	14.45
Michigan	Allegan	20.87	18.32	18.60
Michigan	Bay	21.01	18.82	19.05
Michigan	Berrien	19.87	17.88	18.09
Michigan	Genesee	20.12	17.55	17.73
Michigan	Ingham	20.70	18.22	18.39
Michigan	Kalamazoo	21.89	19.73	19.92
Michigan	Kent	24.48	22.18	22.38
Michigan	Lenawee	19.74	17.48	17.58
Michigan	Macomb	22.60	20.79	20.97
Michigan	Manistee	16.56	14.46	14.65
Michigan	Missaukee	15.03	13.13	13.30
Michigan	Monroe	22.07	19.81	19.94

State	County	2016 Daily $PM_{2.5}$ Design Value (ug/m³)	2045 ctl Daily $PM_{2.5}$ Design Value (ug/m³)	2045 ref Daily $PM_{2.5}$ Design Value (ug/m³)
Michigan	Oakland	22.47	20.22	20.39
Michigan	St. Clair	21.99	19.83	19.93
Michigan	Washtenaw	20.89	18.72	18.89
Michigan	Wayne	26.99	23.77	24.00
Minnesota	Anoka	18.92	17.44	17.51
Minnesota	Becker	16.21	15.42	15.46
Minnesota	Beltrami	15.55	14.73	14.81
Minnesota	Carlton	14.83	13.86	13.94
Minnesota	Cook	11.63	10.87	10.92
Minnesota	Crow Wing	16.04	14.75	14.83
Minnesota	Dakota	17.18	15.82	15.99
Minnesota	Hennepin	19.38	17.60	17.74
Minnesota	Lake	12.27	11.49	11.53
Minnesota	Lyon	16.01	13.55	13.83
Minnesota	Olmsted	17.79	15.74	15.92
Minnesota	Ramsey	20.97	18.71	18.82
Minnesota	Saint Louis	16.34	15.19	15.27
Minnesota	Scott	16.87	15.46	15.57
Minnesota	Stearns	16.59	15.19	15.29
Minnesota	Washington	19.53	17.99	18.16
Minnesota	Wright	17.54	16.02	16.20
Mississippi	DeSoto	16.03	13.81	13.94
Mississippi	Forrest	17.75	15.98	16.08
Mississippi	Grenada	14.95	12.96	13.07
Mississippi	Hancock	18.03	16.18	16.33
Mississippi	Harrison	17.20	15.51	15.61
Mississippi	Hinds	19.17	17.37	17.52
Mississippi	Jackson	17.32	15.77	15.92
Missouri	Buchanan	19.03	16.78	16.97
Missouri	Cass	17.09	15.47	15.61
Missouri	Cedar	16.76	14.81	14.91
Missouri	Clay	16.18	14.39	14.53
Missouri	Greene	16.23	14.63	14.75
Missouri	Jackson	19.72	17.67	17.77
Missouri	Jefferson	20.51	17.51	17.72
Missouri	Saint Louis	20.94	18.31	18.47
Missouri	St. Louis City	21.51	18.98	19.16
Montana	Fergus	25.16	24.48	24.51
Montana	Flathead	42.71	40.64	40.75
Montana	Gallatin	30.47	30.39	30.40
Montana	Lewis and Clark	42.36	41.11	41.17
Montana	Lincoln	45.30	42.91	43.05
Montana	Missoula	44.76	42.36	42.49
Montana	Phillips	24.63	24.04	24.06
Montana	Powder River	27.11	26.23	26.28
Montana	Ravalli	57.57	56.90	56.93
Montana	Richland	22.00	21.45	21.46
Montana	Rosebud	25.69	25.28	25.29

State	County	2016 Daily $PM_{2.5}$ Design Value (ug/m³)	2045 ctl Daily $PM_{2.5}$ Design Value (ug/m³)	2045 ref Daily $PM_{2.5}$ Design Value (ug/m³)
Montana	Silver Bow	35.17	33.86	33.94
Nebraska	Douglas	20.32	17.21	17.38
Nebraska	Hall	14.23	12.91	12.96
Nebraska	Lancaster	17.21	14.98	15.11
Nebraska	Sarpy	18.95	17.03	17.13
Nebraska	Washington	15.94	13.66	13.78
Nevada	Carson City	18.34	17.58	17.65
Nevada	Clark	24.17	23.55	23.53
Nevada	Douglas	27.73	26.30	26.40
Nevada	Washoe	25.02	24.10	24.17
New Hampshire	Belknap	10.20	8.94	8.98
New Hampshire	Cheshire	20.22	18.72	18.75
New Hampshire	Grafton	14.58	13.35	13.41
New Hampshire	Hillsborough	11.71	10.34	10.40
New Hampshire	Rockingham	13.84	12.19	12.31
New Jersey	Atlantic	16.41	15.25	15.30
New Jersey	Bergen	22.32	20.83	20.86
New Jersey	Camden	24.14	21.75	21.81
New Jersey	Essex	21.13	19.96	19.99
New Jersey	Gloucester	20.57	18.97	19.02
New Jersey	Hudson	20.84	19.74	19.78
New Jersey	Mercer	19.54	17.84	17.88
New Jersey	Middlesex	18.60	17.03	17.11
New Jersey	Morris	15.61	14.12	14.17
New Jersey	Ocean	17.34	15.12	15.20
New Jersey	Passaic	19.72	18.33	18.36
New Jersey	Union	22.61	21.63	21.67
New Jersey	Warren	21.74	20.27	20.32
New Mexico	Bernalillo	18.81	18.51	18.52
New Mexico	Dona Ana	27.42	27.54	27.57
New Mexico	Lea	15.91	15.56	15.59
New York	Albany	18.08	16.41	16.48
New York	Bronx	21.70	20.43	20.46
New York	Chautauqua	15.03	13.55	13.61
New York	Erie	18.11	15.92	16.00
New York	Essex	11.09	9.61	9.64
New York	Kings	19.10	18.02	18.05
New York	Monroe	16.47	14.81	14.87
New York	New York	23.29	22.00	22.03
New York	Onondaga	14.11	12.53	12.59
New York	Orange	15.84	14.63	14.66
New York	Queens	18.58	17.25	17.29
New York	Richmond	18.40	17.33	17.37
New York	Steuben	12.41	10.47	10.53
New York	Suffolk	17.00	15.59	15.62
North Carolina	Buncombe	22.48	20.93	21.05
North Carolina	Catawba	19.44	18.56	18.63
North Carolina	Cumberland	17.16	15.69	15.83

State	County	2016 Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ctl Daily $PM_{2.5}$ Design Value (ug/m^3)	2045 ref Daily $PM_{2.5}$ Design Value (ug/m^3)
North Carolina	Davidson	19.43	18.04	18.17
North Carolina	Durham	18.31	16.83	17.02
North Carolina	Forsyth	16.46	14.97	15.11
North Carolina	Guilford	16.13	15.09	15.22
North Carolina	Jackson	27.77	26.32	26.39
North Carolina	Johnston	15.38	13.80	13.93
North Carolina	Mecklenburg	18.40	17.41	17.55
North Carolina	Mitchell	20.60	19.12	19.22
North Carolina	Montgomery	14.47	13.08	13.20
North Carolina	New Hanover	13.64	12.42	12.51
North Carolina	Pitt	14.13	12.79	12.89
North Carolina	Swain	25.70	24.54	24.61
North Carolina	Wake	17.63	16.48	16.62
North Dakota	Billings	16.26	15.59	15.60
North Dakota	Burke	21.23	19.91	19.92
North Dakota	Burleigh	18.83	17.60	17.62
North Dakota	Cass	17.53	16.34	16.39
North Dakota	Dunn	20.57	19.48	19.50
North Dakota	McKenzie	18.06	17.38	17.40
North Dakota	Mercer	16.28	15.51	15.53
North Dakota	Oliver	17.38	16.49	16.51
North Dakota	Williams	21.01	20.22	20.24
Ohio	Allen	19.08	16.98	17.10
Ohio	Athens	14.12	11.95	12.03
Ohio	Belmont	16.17	14.06	14.12
Ohio	Butler	22.63	20.88	21.00
Ohio	Clark	19.81	17.61	17.72
Ohio	Cuyahoga	24.37	22.17	22.21
Ohio	Franklin	19.86	17.79	17.91
Ohio	Greene	18.16	16.52	16.65
Ohio	Hamilton	22.06	19.99	20.11
Ohio	Jefferson	24.61	21.89	21.97
Ohio	Lake	16.76	14.77	14.88
Ohio	Lawrence	15.66	14.26	14.34
Ohio	Lorain	18.60	16.80	16.93
Ohio	Lucas	21.32	19.07	19.25
Ohio	Mahoning	20.90	18.58	18.73
Ohio	Medina	18.69	16.22	16.46
Ohio	Montgomery	19.92	17.80	17.95
Ohio	Portage	17.02	14.57	14.73
Ohio	Preble	17.94	15.72	15.85
Ohio	Scioto	18.50	16.35	16.45
Ohio	Stark	22.14	19.82	19.95
Ohio	Summit	21.92	19.72	19.81
Ohio	Trumbull	18.10	15.50	15.67
Oklahoma	Cleveland	18.43	16.69	16.75
Oklahoma	Comanche	16.16	14.69	14.74
Oklahoma	Kay	17.97	16.60	16.67

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Oklahoma	Oklahoma	18.70	17.04	17.09
Oklahoma	Pittsburg	19.07	17.22	17.29
Oklahoma	Sequoyah	17.89	16.59	16.68
Oklahoma	Tulsa	21.57	19.81	19.91
Oregon	Crook	39.02	36.81	37.00
Oregon	Harney	32.78	31.15	31.26
Oregon	Jackson	52.58	48.94	49.22
Oregon	Josephine	42.58	39.19	39.46
Oregon	Klamath	45.98	44.24	44.39
Oregon	Lake	41.67	40.33	40.43
Oregon	Lane	41.07	39.39	39.53
Oregon	Multnomah	22.41	21.68	21.74
Oregon	Washington	27.01	26.52	26.54
Pennsylvania	Adams	20.10	18.53	18.57
Pennsylvania	Allegheny	35.96	33.70	33.76
Pennsylvania	Armstrong	21.11	18.94	19.01
Pennsylvania	Beaver	20.70	18.76	18.83
Pennsylvania	Berks	25.37	23.84	23.88
Pennsylvania	Blair	22.60	20.41	20.45
Pennsylvania	Bradford	16.87	15.64	15.71
Pennsylvania	Cambria	24.24	22.08	22.10
Pennsylvania	Centre	19.87	17.74	17.81
Pennsylvania	Chester	23.32	21.94	22.00
Pennsylvania	Cumberland	25.40	24.09	24.12
Pennsylvania	Dauphin	26.06	24.24	24.28
Pennsylvania	Delaware	24.80	23.29	23.35
Pennsylvania	Erie	19.56	17.27	17.34
Pennsylvania	Greene	13.53	11.53	11.58
Pennsylvania	Lackawanna	19.47	18.83	18.92
Pennsylvania	Lancaster	28.16	26.62	26.66
Pennsylvania	Lebanon	29.03	27.11	27.17
Pennsylvania	Lehigh	22.47	20.99	21.03
Pennsylvania	Mercer	21.44	19.07	19.19
Pennsylvania	Monroe	18.20	16.63	16.74
Pennsylvania	Northampton	23.64	22.33	22.39
Pennsylvania	Philadelphia	24.13	22.55	22.63
Pennsylvania	Tioga	16.95	15.26	15.34
Pennsylvania	Washington	20.27	18.61	18.64
Pennsylvania	Westmoreland	19.38	17.49	17.53
Pennsylvania	York	22.92	21.48	21.52
Rhode Island	Kent	13.58	11.99	12.05
Rhode Island	Providence	19.45	17.99	18.04
Rhode Island	Washington	14.62	13.01	13.10
South Carolina	Charleston	15.80	14.92	15.01
South Carolina	Chesterfield	15.02	13.59	13.72
South Carolina	Edgefield	18.57	16.55	16.75
South Carolina	Florence	17.23	15.42	15.62
South Carolina	Greenville	23.13	22.28	22.46

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South Carolina	Lexington	18.88	17.43	17.56
South Carolina	Richland	16.87	15.38	15.49
South Carolina	Spartanburg	16.72	15.78	15.90
South Dakota	Brookings	13.62	12.32	12.41
South Dakota	Brown	15.17	14.07	14.13
South Dakota	Codington	15.78	14.32	14.36
South Dakota	Custer	14.43	14.16	14.18
South Dakota	Hughes	12.45	11.91	11.92
South Dakota	Jackson	14.19	13.48	13.50
South Dakota	Minnehaha	17.14	15.07	15.22
South Dakota	Pennington	21.84	20.44	20.52
South Dakota	Union	17.70	15.55	15.72
Tennessee	Blount	23.72	22.22	22.38
Tennessee	Davidson	18.50	16.89	17.05
Tennessee	Dyer	14.16	12.62	12.72
Tennessee	Hamilton	17.91	16.48	16.61
Tennessee	Knox	32.86	30.80	31.05
Tennessee	Lawrence	14.21	12.55	12.66
Tennessee	Loudon	20.37	18.48	18.72
Tennessee	Madison	14.61	13.05	13.18
Tennessee	Maury	14.70	12.74	12.91
Tennessee	McMinn	20.18	18.19	18.35
Tennessee	Montgomery	16.87	14.94	15.11
Tennessee	Putnam	16.91	15.27	15.41
Tennessee	Roane	16.80	14.91	15.05
Tennessee	Shelby	17.87	16.34	16.46
Tennessee	Sullivan	15.62	14.65	14.72
Tennessee	Sumner	16.54	14.34	14.51
Texas	Bexar	19.47	18.86	18.89
Texas	Cameron	25.17	25.03	25.06
Texas	Dallas	18.80	17.16	17.23
Texas	El Paso	23.76	25.27	25.29
Texas	Galveston	21.42	19.88	19.96
Texas	Harris	22.73	21.66	21.76
Texas	Harrison	17.30	15.57	15.65
Texas	Hidalgo	26.37	25.73	25.75
Texas	Nueces	24.86	24.05	24.09
Texas	Tarrant	17.87	16.45	16.50
Texas	Travis	20.33	18.77	18.84
Utah	Box Elder	32.47	31.04	31.09
Utah	Cache	32.80	31.79	31.83
Utah	Davis	30.28	29.70	29.66
Utah	Duchesne	24.72	23.91	23.96
Utah	Salt Lake	37.57	36.06	36.04
Utah	Tooele	25.53	24.77	24.80
Utah	Utah	30.97	30.48	30.42
Utah	Washington	13.95	13.29	13.41
Utah	Weber	31.52	29.91	29.89

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Vermont	Bennington	13.62	12.26	12.32
Vermont	Chittenden	13.78	12.75	12.77
Vermont	Rutland	22.48	21.71	21.75
Virginia	Albemarle	14.81	13.15	13.20
Virginia	Arlington	18.11	17.02	17.05
Virginia	Bristol City	18.14	17.12	17.18
Virginia	Charles	14.62	12.91	13.04
Virginia	Chesterfield	16.00	15.05	15.09
Virginia	Fairfax	17.20	15.71	15.75
Virginia	Frederick	19.94	18.76	18.81
Virginia	Hampton City	14.53	12.99	13.09
Virginia	Henrico	15.52	13.61	13.71
Virginia	Loudoun	17.20	16.48	16.51
Virginia	Lynchburg City	14.18	12.52	12.62
Virginia	Norfolk City	14.37	12.70	12.78
Virginia	Roanoke	15.73	14.11	14.19
Virginia	Rockingham	18.60	17.17	17.23
Virginia	Salem City	15.86	14.18	14.29
Virginia	Virginia Beach City	15.69	14.12	14.21
Washington	Chelan	21.37	20.24	20.32
Washington	King	28.37	28.47	28.47
Washington	Kitsap	17.53	17.40	17.41
Washington	Kittitas	39.83	37.65	37.82
Washington	Okanogan	62.40	56.79	57.02
Washington	Pierce	30.76	30.50	30.52
Washington	Skagit	15.62	15.34	15.36
Washington	Snohomish	34.46	33.35	33.44
Washington	Spokane	32.22	31.15	31.22
Washington	Whatcom	17.90	17.43	17.46
Washington	Yakima	43.70	40.42	40.64
West Virginia	Berkeley	24.08	22.77	22.80
West Virginia	Brooke	21.73	19.66	19.74
West Virginia	Hancock	19.87	17.31	17.37
West Virginia	Harrison	16.80	15.19	15.24
West Virginia	Kanawha	16.92	15.63	15.67
West Virginia	Marshall	21.80	19.92	20.00
West Virginia	Monongalia	17.52	15.64	15.70
West Virginia	Ohio	18.02	15.74	15.82
West Virginia	Wood	17.98	15.81	15.90
Wisconsin	Ashland	13.51	12.22	12.34
Wisconsin	Brown	19.50	17.35	17.59
Wisconsin	Dane	21.66	19.30	19.57
Wisconsin	Dodge	19.74	17.63	17.89
Wisconsin	Eau Claire	17.68	15.67	15.87
Wisconsin	Forest	12.73	11.15	11.32
Wisconsin	Grant	20.32	17.36	17.66
Wisconsin	Kenosha	19.23	17.44	17.58
Wisconsin	La Crosse	18.69	16.66	16.86

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Wisconsin	Milwaukee	22.22	20.28	20.44
Wisconsin	Outagamie	20.03	17.12	17.40
Wisconsin	Ozaukee	18.32	16.57	16.74
Wisconsin	Sauk	17.61	15.49	15.70
Wisconsin	Taylor	15.36	13.59	13.73
Wisconsin	Vilas	15.07	13.21	13.45
Wisconsin	Waukesha	21.16	19.12	19.38
Wyoming	Albany	13.08	12.59	12.61
Wyoming	Campbell	17.33	16.92	16.94
Wyoming	Fremont	23.07	22.38	22.42
Wyoming	Laramie	13.37	12.94	12.95
Wyoming	Natrona	15.37	14.81	14.84
Wyoming	Park	20.69	20.37	20.39
Wyoming	Sheridan	23.16	22.46	22.51
Wyoming	Sublette	16.27	16.04	16.05
Wyoming	Sweetwater	17.97	17.01	17.04
Wyoming	Teton	15.48	15.22	15.25